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AMERICAN REVOLUTION BICENTENNIAL 1776-1976

Readiness Through Simulation

PROCEEDINGS

NOVEMBER 9-11, 1976

9th NTEC/Industry Conference

NAVAL TRAINING EQUIPMENT CENTER • ORLANDO, FLORIDA 32813

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A compilation of papers on a variety of technical and training subjects related to training device technology and training methodology. The papers in this report were presented at the Ninth NTEC/Industry Conference held 9-11 November 1976. The Conference theme "Readiness Through Simulation" was selected to explore the vital role that simulation plays in developing and maintaining the effectiveness and readiness of our operational forces. The Ninth conference is part of a continuing program to promote cooperation between Government and

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industry in the procurement of training equipment, and to foster an exchange of ideas on new simulation technology.

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FOREWORD

The theme for this year's conference, "Readiness Through Simulation," has been selected not only because it supports the bicentennial theme, but also because of the vital role that training plays in maintaining the operational readiness of our armed forces. This year's theme also focuses attention not only on what research, development, and acquisition of training systems will mean in terms of maintaining operational readiness for weapons systems currently under development, but also because it stresses the substantial role that the existing inventory plays in supporting weapons systems which are currently in the field. It also focuses attention on the need for keeping an aging inventory current with the operational systems which they support and ensuring their availability through an adequate support posture.

The development of training systems to support new weapons systems must constantly be tested against effectiveness criteria to ensure that training needs are satisfied through most cost-effective systems based on viable alternatives. There is a need for a strong research and development program to ensure that risk areas, both with respect to technology and methodology of training, are fully explored before commitments are made for the acquisition of training equipment.

It is the goal of this conference, through the papers which have been selected for presentation, to encourage a constructive dialogue to take place so that the readiness of our operational forces can be maintained through cost-effective training systems.

G.V. Amico

G. V. AMICO
Conference General Chairman

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INTRODUCTION TO THE CONFERENCE

G. V. Amico
Director of Engineering
Naval Training Equipment Center

The theme of this year's conference, "Readiness Through Simulation," is fitting since it emphasizes the vital role that training, and particularly training equipment, plays in a peacetime environment. This theme not only permits us to objectively assess capabilities and shortcomings of the inventory of training equipment, but also enables us to project capabilities of future systems. While previous conferences have placed emphasis on product improvement and training effectiveness of future training systems, I plan to assess the capabilities of training systems already in the inventory which are located at formal schools and fleet activities. This evaluation of the inventory will also focus attention on those factors which could improve the training effectiveness and supportability of these systems.

First, I would like to spend a few moments presenting information on the capabilities which exist in the present inventory. This training capability is achieved through a Navy/Marine Corps inventory of $683 million of training equipment representing 2,844 trainers with an acquisition value of over $1,000 each. I have translated the extensive utilization data which are collected and processed on 290 of the major devices by the Naval Training Equipment Center for the Chief of Naval Operations into another domain; namely, that of equivalent operational training, including the magnitude of threat and number of simulated weapons which are fired in synthetic training exercises.

These training systems were designed to provide individual operator, team, and task force training on one, or a combination of today's complex weapons systems. The training tasks range from cognitive and psychomotor skills through complex decision-making tasks including the collection of intelligence, evaluation of data, and deployment of platforms and weapons to cope with threats. The training systems provide instruction in a controlled environment where learning situations can be manually or automatically adapted to the proficiency level of the trainees. The instantaneous disposition of forces through initialization and reset features of the devices permits economic repetition of difficult and critical tasks.

The 290 devices covered in the utilization reporting system provided 245,055 hours of training in FY 76 with an average availability of 87 percent. In some cases, it has been necessary to run the trainers for two shifts to accommodate the student load.

The aviation trainer inventory consisted of 125 major trainers which provided 140,000 hours of flight simulation for 21 types of aircraft. Flight crews had to cope with over 100,000 emergencies. Thirty-two thousand carrier landings were made. There were 16,000 engagements against 37,000 air targets and over 63,000 air-to-air missiles were fired. A total of 46,000 hours of air ASW missions were flown against 15,000 submarine targets in which 96,000 sonobuoys, 2,000 torpedoes, and 13,000 depth charges were expended.

Moving to the surface ship trainers, the statistics are equally impressive. Eighty-six surface ship trainers steamed for 140,000 hours. All of this time was devoted to tactical AAW, ESM, and ASW training problems. These surface ships were augmented by 54 support ships and 34 fixed-wing aircraft and helicopters. The crews were defending against air and submarine threats. The threats consisted of 34 aircraft and 40 submarines. In these exercises, 45,000 weapons of various types were fired.

Submarine trainers operated for 21,000 hours. During this time there were 25,000 diving and surfacing evolutions. Crews corrected more than 50,000 malfunctions. Attack submarines detected, tracked, and attacked 10,000 target submarines and fired 20,000 torpedoes of various types.

There is another segment of the inventory which is equally important but not as glamorous as the complex trainers. These items are the individual and classroom training aids and devices which are used to support individual self-paced or classroom instruction.

Although the record of training accomplished with the existing inventory is impressive, there are a number of shortcomings which must be addressed. These shortcomings reduce the overall effectiveness of the training programs which are being supported. There are four major problem areas associated with the inventory. One or more of these deficiencies may exist on any one system. The four areas are: (1) systems no longer meet current training objectives, (2) reliability and supportability of training systems,

(3) inventory obsolescence and, (4) training systems in which Operational System Equivalence Ratio (OSER) is less than unity.

I have introduced the term OSER to identify the problem associated with keeping training systems current with their operational counterparts, both with respect to hardware and computer software. This area is usually referred to as the configuration management problem.

The severity of the problems enumerated above is influenced by the age of the inventory and the uniqueness of its composition. To indicate the severity problem, 26 percent of the inventory is over 10 years old and 57 percent is over 5 years old. The inventory that is over 5 years old represents analog and discrete component digital systems technology which is difficult to maintain. The inventory is made up of 1,126 different devices out of a population of 2,844 which further complicates life-cycle support.

The statistics on device utilization are impressive. They point out the success of the training device planning and programming system.

It is this demonstrated performance, coupled with the future potential of training systems, that has been a major factor in the rationale which leads to the emphasis being placed on training device acquisition programs today. The value of these systems cannot be properly expressed by their acquisition value. The true value can only be measured by the contribution they make to operational readiness of our forces.

On behalf of the Naval Training Equipment Center, I would now like to extend appreciation for the support and cooperation we have received from both Government agencies and Industry. Thirty papers, covering a wide range of subject matter in the areas of research, development, design and testing of training systems will be presented during the next three days. I would also like to express my sincere appreciation for the time and effort that the authors have contributed in preparing the papers which will be presented. These papers provide the basis for achieving the conference goal; an effective exchange of information and ideas between sponsors, users, operators, and producers of training systems so that operational readiness can be improved through simulation.

ABOUT THE AUTHOR

MR. G. VINCENT AMICO has been Director of Engineering at the Naval Training Equipment Center since 1971. He graduated from New York University with a Bachelor of Aeronautical Engineering in 1941. He was awarded a Masters in Business Administration from Hofstra College in 1954 and a Master of Science in Engineering from Florida Technological University in 1973. Mr. Amico worked on the design of naval aircraft as a stress analyst and project stress engineer with the Curtiss-Wright Corporation from 1941 to 1945. He entered the Armed Forces in 1945 and was assigned to the Static Test Unit of the Structures Laboratory at Wright Field as a structure research engineer. Upon leaving the service in 1947, Mr. Amico joined Republic Aviation Corporation with responsibility for preliminary design of missile and advanced aircraft systems. He joined the Center in the fall of 1948 as a project engineer in the Flight Trainers Branch. Since then he has progressed through the engineering organization, holding positions as Head of the VA-VP OFT Branch; Head of the Aviation Trainers Division; Deputy Director and Chief Engineer of the Special Projects Office and Director of the Sea Warfare Trainers Department. During this time, he was responsible for the development and production of a wide variety of training devices in all warfare areas. Mr. Amico is a member of Tau Beta Pi and Alpha Pi Mu Honorary Engineering Fraternities, American Society of Military Engineers, Society for Experimental Stress Analysis, Research Society of America, Sigma Xi, the American Institute for Aeronautics and Astronautics, and the Armed Forces Communications and Electronics Association. He was past Chairman of the New York section of the Institute of Aerospace Science and the Orange Chapter of the Armed Forces Communications and Electronics Association. Mr. Amico holds two patents and has presented a paper to the Institute of Radio Engineers on Synthetic Training for Space Flight. He co-authored a paper on "The Application of System Dynamics Techniques to the Modeling of the Military Training System" for The Seventh Annual Simulation Symposium.

SYSTEM DEVELOPMENT OF A SHIP HANDLING SIMULATOR

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Great Neck, New York

The U. S. Merchant Fleet is an essential element of our commerce and defense. American Flag vessels operate under very stringent regulations governing vessel safety and the protection of life at sea. However, collisions and groundings involve a significant number of vessels each year. This constitutes a problem which warrants an organized effort toward solution.

Research to identify causes and define solutions to problems such as collisions and groundings is a natural application for simulation. The conditions of an experiment can be controlled, and results observed more accurately than if actual vessels were used. Study variables can be changed over wide ranges. New equipments and procedures can be investigated more easily and quickly in a simulator than in the real world. Potential risk situations can be investigated without endangering either the "own ship" or other traffic. Also, the cost of simulation is generally much less than the cost of a comparable study using full-scale ships in an actual harbor or seaway.

With this research in mind, the U. S. *Maritime Administration* in mid-1971 authorized Sperry Systems Management, a division of Sperry Rand Corporation, to conduct studies toward the development of a marine research simulator. These studies affirmed the concept of simulation based research and defined the overall configuration. Hardware and software development was authorized in mid-1973. The resulting system was delivered by Sperry in December 1975, and put in operation for the National Maritime Research Center of the Maritime Administration.

The Computer Aided Operations Research Facility (CAORF), is designed to conduct navigational and ship handling experiments to enhance the safety, productivity, and competitiveness of the American Merchant Marine. Some of the system engineering aspects of CAORF are covered in this paper. System requirements are considered first, followed by discussions of the functions of the major subsystems and the overall configuration, and how each contributes to fulfillment of the system requirements.

SYSTEM REQUIREMENTS

The system requirements for a research simulator are somewhat broader than the requirements for a simulator which is used primarily for training. Much of the investigation of the causes of collisons and groundings, for example, must focus on the performance of the crew on the bridge and the man-machine interface at the bridge, under high-stress maritime situations. The research simulator must:

1) Simulate each of the operational and environmental factors which significantly affect the performance of the bridge crew

2) Simulate each of these factors with sufficient realism to produce valid results

3) Provide flexibility to permit rapid changes in these factors

4) Include the capability for recording and storing information from each experiment for study and analysis.

There are other requirements; however, these are among the most critical.

Referring to the first of these requirements, the important elements of maritime operation which *affect the bridge crew, and which* should be simulated realistically, include:

- Instrumentation and the layout of the bridge
- Ship's performance and "feel;" i.e., its propulsion and steering dynamics, and hydrodynamic characteristics
- Configuration of the harbor or seaway in which the ship is operating
- Navigation aids, cultural features, and important landmarks which are visible from the bridge
- Other ship traffic; types of ships, courses, maneuvers
- Communications from the "own ship's" engine room, other ship traffic, and shore facilities
- Visibility; fog, haze, day, or night
- Unexpected breakdowns of ship equipment; propulsion, steering, and electric power.
- Color of objects in the scene.

Referring to the second requirement, realism of simulation requires that the bridge crew be surrounded by realistic equipment, and that the sights and sounds of the real world situation be adequately reproduced. For a research simulator which focuses on crew performance, realism also requires that the "mood" or atmosphere of the real world situation be established and maintained throughout the simulation. For example, insofar as is feasible, the approaches to the simulation area should have a maritime decor similar to a ship's passageways. Once the simulation is started, it should not be interrupted by external disturbances nor breakdowns of simulator equipment. Apart from the impact of availability on simulator operating economics, high availability is an essential requirement for adequate realism.

The third requirement implies flexibility at several levels. During an experiment, for example, the simulator should be capable of changes in weather and visibility, and in the number and types of traffic ships. It should be possible to make changes such as bridge arrangement, dynamic characteristics of "own ship," configuration of navigation aids, or minor cultural features, between parts of an experiment. Major changes, in harbor configuration, or the experiment gaming area, should be possible in a reasonably short time between experiments. Over a long period of time, it should be possible to add new equipments and capabilities to the simulator in order to permit evaluation of proposed advances in the state-of-the-art.

To meet the fourth requirement, the simulator system should include, in addition to conventional recording and printout or plotting capabilities, some means for recreating and observing portions of the experiment activities for detailed study and analysis.

The configuration and operation of the major CAORF elements are described next to show how CAORF meets the four basic requirements above.

WHEELHOUSE AND BRIDGE

The bridge crew operates in a full-scale "own ship's" wheelhouse, fully equipped with contemporary instrumentation and controls. The engine order telegraph, steering stand, and other bridge instruments and controls are current commercial models selected after a survey, to identify those types which are in widespread use on U. S. Flag vessels. Standard marine radar units are located on the bridge (see Figure 1). Wheelhouse construction is such that all bridge equipment is easily moveable so that the arrangement can be changed. Units can be added or deleted when it is desired to study the effect of a particular arrangement or unit on the performance of the bridge crew, or on the outcome of a particular situation. Bow and stern thrusters and twin screw controls are available.

Figure 1. Interior of wheelhouse showing bridge equipment

The wheelhouse is located at the center of a 60-foot diameter circular theater. On the walls of the theater, covering a 240-degree field of view, is the scene which is observed through the wheelhouse windows at the actual position and heading of the "own ship." As the "own ship" moves in response to the commands of the bridge crew, the scene changes appropriately. As many as six other moving traffic ships of various types can appear simultaneously in the scene. Up to 40 traffic ships can appear simultaneously in the radar display, since the radar can scan a much greater area than can be seen visually. The bridge is equipped with intercom and sound-powered phones for simulated communication to the engine room and other parts of "own ship," a ship's whistle, and radio equipment for communication with other traffic ships and shore installations.

Figure 2 shows the arrangement of the wheelhouse and the other major elements of the simulator within the CAORF building. The building was designed and delivered as part of the CAORF system. It increases the effectiveness of the system by providing a benign physical environment, maritime decor to enhance the mood, and an efficient arrangement for operation and maintenance.

CENTRAL DATA PROCESSOR

A central computer simulates propulsion and steering dynamics and hydrodynamics. It then solves the equations of motion of "own ship" in order to update the "own ship's" position and heading. The computer also updates the positions and headings of the traffic ships in the experiment. These are under the command of the Experiment Controller who is located in the Control Station, separate from the bridge crew. The computer sends the updated positions and headings of all of the ships plus information on sunlight and weather,

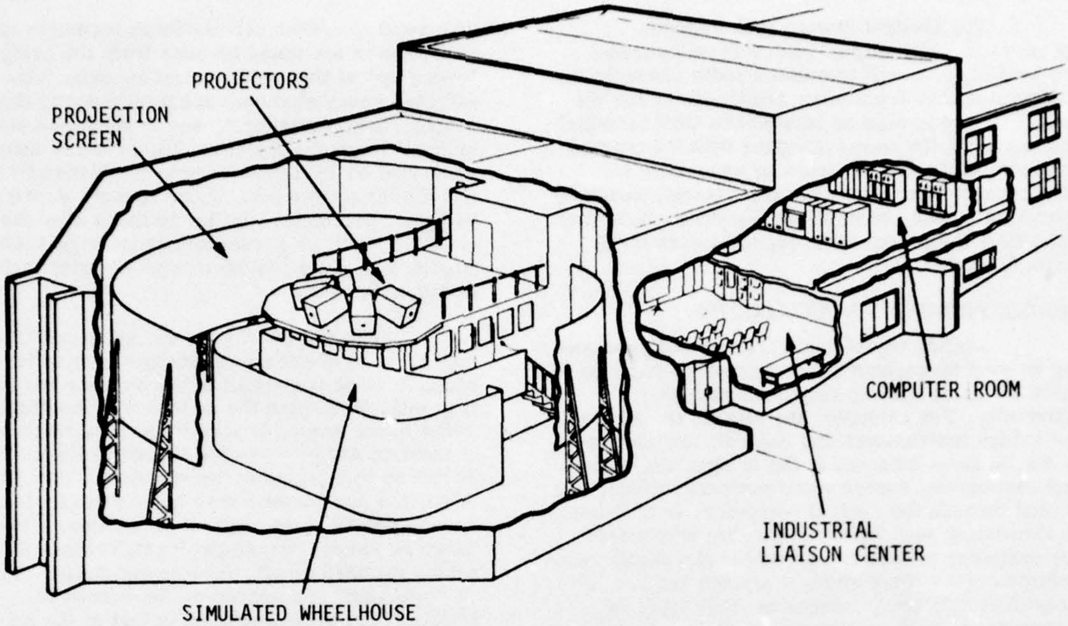

Figure 2. Cutaway view showing arrangement of elements of CAORF simulator in its building.

thirty times per second, to the appropriate bridge and control station instruments, three other dedicated computers which generate the visual scene, the radar displays on the bridge, and a map-like situation display in the Control Station. The central computer also coordinates all commands and data flow throughout the simulator. It records data for analysis and, if desired, playback of any desired portions of the experiment.

CONTROL STATION

The experiment is directed from the Control Station (see Figure 3) where the Experiment Controller and his assistants perform the following functions:

- Start and stop the experiment, change operating modes (e.g., "freeze" or "playback")
- Monitor experiment status and issue commands to the bridge crew as appropriate
- Control the insertion, motion, and the deletion of traffic ships in the visual scene and in the radar presentation
- Perform the functions of the engine room of the "own ship," providing communications, and changing propulsion or steering upon request from the bridge
- Provide voice and whistle communications as appropriate from other traffic ships, other parts of "own ship," and shore installations
- Control the weather, haze, fog, etc.
- Insert simulated failures of "own ship's" propulsion, steering, or electric power.

The Control Station is equipped with an equivalent set of bridge instruments and controls. Instead of a duplicate radar presentation, however, there is a situation display of equivalent size which presents a continually updated map of the experiment gaming area. The map shows shorelines, channels and buoys, and all traffic ships participating in the experiment, with symbolic indications of types, and vectors indicating heading and speed. The Experiment Controller has a choice of several scales and modes of presentation.

Figure 3. Control Station

The Control Station also includes appropriate "own ship's" intercom and sound-powered phones, and simulated radio channels for communications from other traffic ships and the shore. There is also an interactive CRT terminal and keyboard for communicating with the central computer and other controls as necessary for starting and terminating the experiment, changing operating modes, controlling visibility, inserting simulated equipment failures, and performing other functions.

SIGNAL PROCESSING PHILOSOPHY

Digital signal transmission and processing is used throughout the simulator in order to meet the basic system requirements more efficiently. For example, the signals to and from the bridge instruments and controls are converted to digital form adjacent to the bridge. All signals and commands, except voice communications, are routed through the central computer. In addition to simulating such functions as ship responses, the computer is able to coordinate and synchronize related events, thus giving a smooth and realistic overall simulation. Changes in many types of parameters, such as changes in ship's characteristics, insertion and deletion of traffic ships, and changes in types of ships, are facilitated by the use of digital data. This computer-centered configuration also facilitates the storage of information from the experiment for analysis.

As many as several hundred quantities can be recorded, if desired; the rate of recording can be selected by the Experiment Controller and varied during an experiment. There is also a playback mode where the experiment can be frozen at any time, and any previous portion can be repeated for instance, all simulated motion of "own ship" and traffic ships, visual and instrument displays, and changes in propulsion and steering commands are repeated in real-time for observation and analysis. Playback can be exercised during an experiment or at a later date. Figure 4 is a CAORF system functional flow diagram.

In an extension of this system philosophy, computer generated imagery (CGI) is used to create the three visual displays; the maritime scene in the theater viewed through the wheelhouse windows, the radar displays on the bridge, and the situation display in the control station. Each of these displays is generated by a separate, dedicated computer which is under the control of the central data processor. The use of separate data bases for the three displays was found to be more efficient. The visual scene is the most extensive of the three; its operation will be discussed next.

IMAGE GENERATOR AND DISPLAY

The data base for the visual scene is stored in the dedicated computer. When the position and heading of the "own ship" is received from the central data processor, the dedicated computer selects those elements of the data base which would be seen from the bridge of "own ship" at that position and heading. The selected scene elements are processed to show the proper range and aspect, and to eliminate elements hidden by closer elements. The scene is then converted to TV raster format for transmission to the display projectors. These operate on the Eidophor principle, similar to those used for closed-circuit TV presentations in large auditoriums. Figure 5 shows a typical computer generated visual scene in CAORF.

The use of CGI greatly enhances CAORF's capability to simulate and change several factors which have an important affect on crew performance. It greatly facilitates the inclusion of moving traffic ships in the scene. It permits total unrestricted movement and perspective change of the scene in response to motions of the simulated "own ships." Also, the eye position may be arbitrarily located in both height, fore, and aft directions. Thus, large or small "own ships," with bridges mounted either forward or aft, may be simulated. The bow of "own ship" can appear on the screen if appropriate; its appearance is that of the selected type of "own ship." To date, two oil tankers and one LNG tanker have been encoded for display. Others can be readily added as the need occurs.

The ambient illumination in the scene is continuously variable from day to night. In daytime scenes, the sun's position is suggested by highlights and shading on buildings, terrain, and other picture elements. In twilight and night scenes, the lights located on ships and on shore are controllable by groups. Each light is represented in its correct color, location, flashing pattern, and visibility range. Lights having a directional characteristic or color changes are so represented.

The area used, in the visual scene, for a single continuous exercise is normally 50 by 100 miles (the radar gaming area is appropriately larger to allow for the greater range of the radar on a ship which is located near the edge of the visual gaming area). If desired, the experiment may shift after a short interruption to a continuous gaming area of equal size. The gaming area represented in the present data base covers the approaches to New York through the narrows and through the Kill Van Kull to Port Newark. When more areas are encoded, exchanging one magnetic disk in the image generator computer will change the visual scene to represent a totally different area.

Within the limits of computer capacity, the scene encoded into the data base can show bridges, piers, buoys, buildings, terrain features, cranes, and other fixed objects of importance to mariners navigating in the harbor. Nautical charts, topographic maps, photographs, and other sources are used to assure the accuracy of presentation as well as the priority of feature selection in terms of importance to the mariner. Provision is made

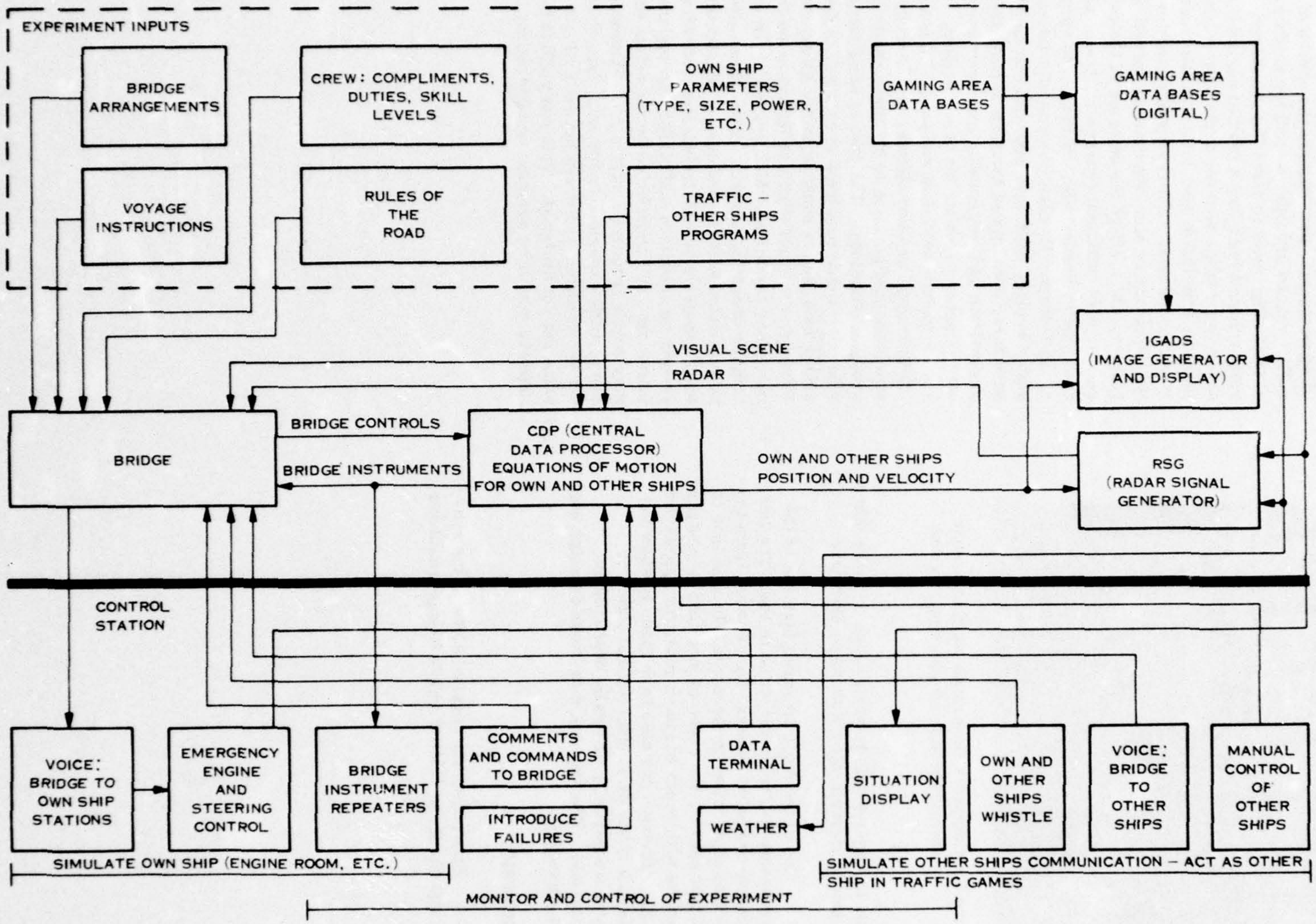

Figure 4. CAORF Functional Flow Diagram

Figure 5. Computer Generated Maritime Scene viewed through wheelhouse windows

to add or remove aids to navigation, or make other changes as warranted by Notices to Mariners.

One of the most dramatic features of the visual system is the presentation of fog. The image generator computer "knows" the distance from the viewer to each object in the scene. In response to a control setting, the scene is modified by contrast reduction with range to give a realistic impression of fog. Provision has also been made to show fog banks in a realistic manner so that lights or objects are partially or totally obscured as appropriate. The fog bank may move or ships may move through it.

CONCLUSION

This paper has covered some of the system aspects of the CAORF ship's bridge simulator. CAORF is designed for research into shiphandling problems, particularly the causes of collisions and groundings, and the performance of the bridge crew in stressful situations. These research problems are a fruitful application which can realize several of the unique advantages of simulation over investigations using real world equipment. The research simulator has the capability to simulate critical operational factors, which affect the outcome of the experiments, with sufficient realism to obtain valid crew performance, with the facility to vary each of the factors. CAORF consists of a full-scale ship's bridge, fully equipped with contemporary hardware, with digital handling of essentially all information and commands, and computer generated imagery to create maritime scenes. The scenes include sufficient numbers of moving traffic ships, weather effects, and harbour waterway configuration to simulate realistic problem situations. The cost of simulating marine operational problems in this way is considerably less than it could be in the actual vessel. Further, the simulation can include complex and hazardous conditions which are out of the question for operating vessels. The experiments can be conducted with the advantages of laboratory tests; properly skilled technicians recording results on scenarios undisturbed by unplanned intrusions, and undeflected by the crisis which may result from such intrusions. Simulation can provide experiments for entry into channels not yet dredged, and docks not yet built for ships not yet designed. This can yield data to improve maritime systems and operations.

ABOUT THE AUTHORS

MR. T. C. HUTCHINSON is Head of the Engineering Department at Sperry Systems Management. He has been manager of the CAORF Program from its inception. His experience includes management of other marine related projects, development of optical systems and radar and electronic warfare systems. Mr. Hutchinson received the B.S. and M.S.E.E. degrees in Physics from the Pennsylvania State University.

DR. M. J. KIRBY is Senior Research Section Head at Sperry Systems Management. He was responsible for systems engineering and systems integration of the CAORF simulator. Previous experience includes systems engineering, feedback control, reliability and logistics engineering on aircraft inertial systems, air-to-air missiles, and preliminary design of space vehicle guidance. Dr. Kirby has a B.S.E.E. degree from Iowa State University, and the M.S. and D.Sc. degrees in Electrical Engineering from Carnegie Institute of Technology.

MR. W. ZDAN is Senior Research Section Head at Sperry Systems Management. He was responsible for the analysis, digital computer selection, ship hydrodynamics, mathematical modeling, and development of the digital computer programs for the CAORF Central Data Processor. His past experience includes participation in the design and development of navigation, guidance, and control systems for the nuclear research submarine NR1, deep submergence rescue vessel (DSRV), Trieste bathyscaphe, Atlas Missile, and various aircraft systems. Mr. Zdan has a B.E.E. degree from Cooper Union Institute of Technology and an M.E.E. degree from Brooklyn Polytechnic Institute of Technology.

GENERATION OF AUDIO SIGNALS FOR SONAR SIMULATION/STIMULATION WITH DIGITAL TECHNIQUES

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Honeywell, Marine Systems Division

ABSTRACT

Sonar signals are conventionally divided into two categories: (1) shaped, broadband components, such as ambient, ship flow and propeller cavitation noises, and (2) narrowband components, including machinery noise, echoes, and reverberations. This paper will explain how Honeywell uses digital data processing to generate these signals for use in sonar trainers.

BROADBAND SPECTRUM SIGNAL GENERATION

For the purpose of this discussion, the broadband spectrum addressed is the bandwidth of 10 Hz to 20 kHz, a spectrum of interest in generating audio signals used in sonar simulation and stimulation. The ocean spectrum is known to have certain predominant shaping in this bandwidth due to wind, shipping, and ocean lift.

The results of recent ambient-noise investigations have been published. The Knudsen curves show the ocean spectrum shaping over the frequency spectrum ranging from 1 Hz to 10^5 Hz. This spectrum may be viewed as a shaped, broadband spectrum. This section discusses an approach used in digital signal processing to synthesize this spectrum. The shaped, broadband spectrum can be subdivided into smaller bands, from which filter networks can be designed, and the overall filter outputs summed to create the shaped broadband spectrum.

One type of filter that can be used to develop the broadband shaping required is a n-pole/m-zero recursive digital filter of the general expression:

$$Y_{out} = \sum_{i=0}^{n} a_i x_i - \sum_{i=1}^{n} b_i y_i \qquad (1)$$

where: Y_{out} = One filter output

a_i = Zero coefficients

x_i = Filter inputs

b_i = Pole coefficients

y_i = Delayed outputs

The first stage in developing this broadband spectrum is to develop a flat response over the bandwidth of interest. This is achieved by using a digital pseudo-random number generator of sufficient length. The pseudo-random generator must then be sampled at a frequency sufficiently high to obtain the desired bandwidth, and also eliminate the unwanted aliasing foldover due to the Nyquist constraint.

The Read-Only Memories provide a table look-up for the filter coefficients, Figure 1. These coefficients also could be a Random Access Memory (RAM), which could be computer-loaded for added filter flexibility. The filter input samples, Figure 2, are then multiplied by the necessary coefficient using a parallel digital multiply algorithm utilizing MSI digital multipliers. These partial products are then summed over the number of poles and zeros in the digital parallel adder to meet the requirements of equation 1. The output of the filter is then sent to a gain adjustment network, which also can be a digital multiplier.

The same constraints in implementing low-pass, band-pass, and high-pass digital filters also apply in this form of spectrum shaping, i.e., the sampling frequency chosen must be sufficiently high to prevent unwanted aliasing and foldover.

The coefficient range must be sufficient to allow proper pole and zero placement. The number of bits carried through the filter must be sufficient to achieve the dynamic range and resolution required by the desired spectrum shape.

Once the desired spectrum shape has been determined, a model can be formed from which a computer simulation can be utilized to determine the coefficient sizes. The attractiveness of this type of digital filter implementation is the flexibility afforded in the selection of the number of poles and zeros required for a particular filter network. The same digital multipliers and adders also can be used for all the filters. This type of implementation is a sampled filter timesharing the multipliers and adders.

The recursive filter is considered to be the most cost-effective approach that will achieve the desired spectrum shape.

NARROWBAND SPECTRUM SIGNAL GENERATION

The basic requirements for narrowband signals used to simulate or stimulate sonar equipment is to generate lines with the following controlled characteristics:

1. Frequency
2. Frequency slide
3. Amplitude
4. Time on/off
5. Line spread
6. Delta phase.

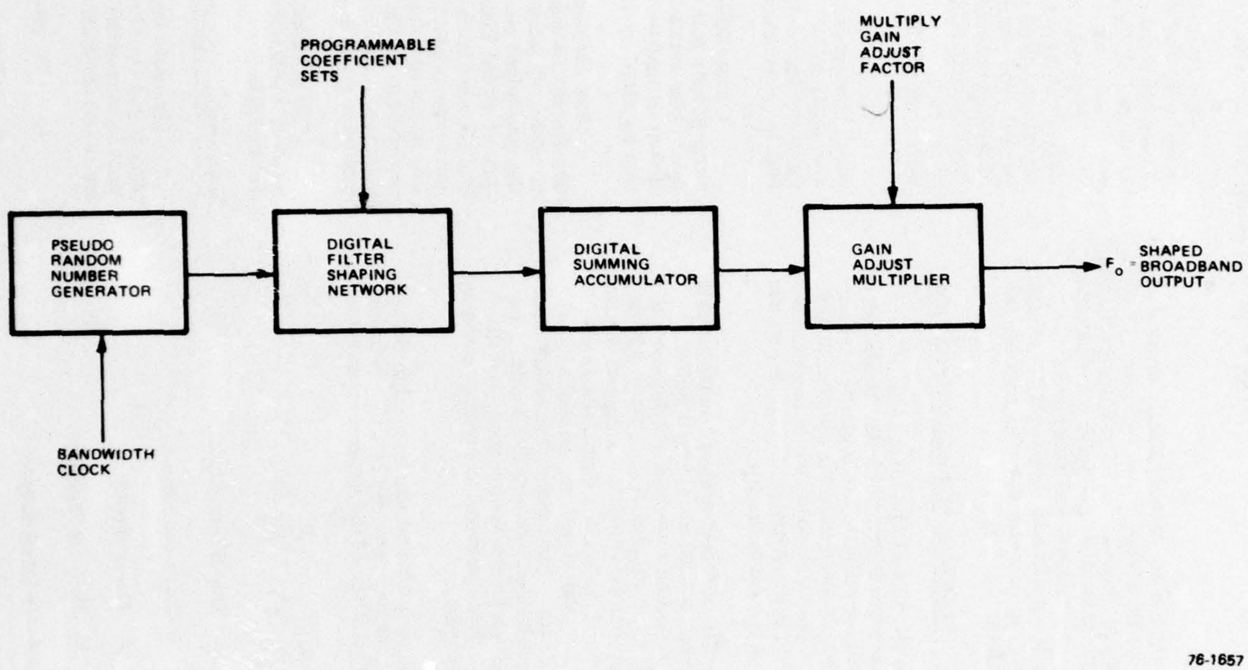

Figure 1. Broadband Digital Audio Model

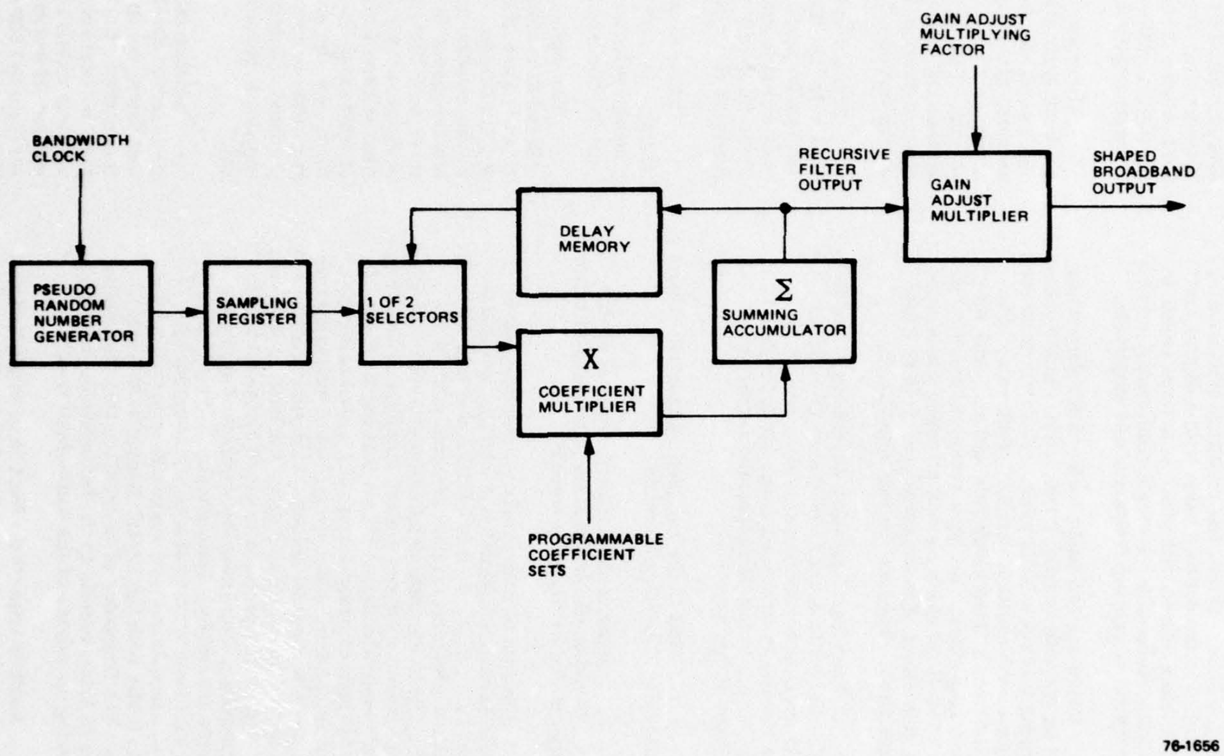

Figure 2. Broadband Digital Audio Model Filter Shaping Network

As may be seen from Figure 3, the approach illustrated in this paper is to use digital techniques to generate and control these signals. First, a sine wave is stored in a Read Only Memory (ROM); second, a step-by-step approximation of a sine wave is generated by extracting sequential values from the ROM. Third, the resulting sine wave is attenuated to the desired value with a digital multiplier and summed with other sine wave points to provide a composite waveform comprising several sine waves of varying frequency and amplitude.

There are two basic methods for generating sine waves with varying frequencies; each involves stepping through a ROM table. The first is to step through a table with a variable clock rate. The second uses a fixed clock rate and step with different step sizes. We have chosen to use the latter. The fixed clock method provides the beneficial side effect of more steps per cycle at lower frequencies. This will be explained later.

To keep high frequency resolution, in addition to the basic count or step size, fractional parts causing a non-integer count, are carried. This results in counts running, for example, 7, 7, 8, 7, 7, 8. Using this technique required the analysis of two questions:

1. What is the harmonic distortion caused by carrying non-integer counts?

2. What is the harmonic content of the wave, based on the fact that the sine wave is being approximated by discrete steps?

Analysis of both problems discloses that (1) the harmonic distortion due to the fact that we count 7, 7, 8, 7, 7, 8 is 44 dB down; this will not create a problem; (2) the harmonic content resulting from discrete point samples, approximating a sine wave, requires a more complex explanation. A computer simulation shows that the first set of bad harmonics are n-1 and n+1, with n being the number of samples per cycle. This means that the sample rate must be selected to ensure that the n-1 and n+1 harmonics are outside the band of interest. Solution of this problem is aided by the fact that, as frequency decreases the number of steps per sample increases. Consequently, this yields a bad harmonic content at a constant frequency. As an example, we are currently generating lines up to 5 kHz with the lowest sample rate being 32 kHz. The frequency of interest, in this particular case (5 kHz), results in the harmonic distortions showing up outside of the band of interest.

Another important effect to be simulated is a frequency slide. For this simulation, the count or frequency of the generated wave is updated once each second by computer control. If it becomes desirable to change frequency during this one-second period, such as a doppler rate change for a target, or a frequency modulated pulse transmission, an additional control is provided; this technique is called delta count. With delta count, a number is added to the count number every iteration for selection of a point in a sine wave. In this manner the frequency can slide up or down. This control also is updated once each second.

After generation, the sine wave is fed to a digital multiplier, Figure 3, with a control word representing amplitude, which is updated once each second from the computer. It is then multiplied (i.e., attenuated) in order to form the final desired amplitude and frequency shaped sine wave.

These are the basic controls by which narrowband generation is accomplished. There are other controls, however, that are necessary as well as some other events that take place (e.g., an active echo) that require on times of less than one second. For these reasons, the computer outputs another control word that, in essence, will be counted down so that once a signal is turned on it can be turned off in increments of one millisecond.

Another important factor of narrowband simulation is that the waves should not be pure sine waves but should have some spreading and fading. This effect is simulated by amplitude modulation of the wave with random numbers that have a Rayleigh distribution.

This, in turn, will cause both spreading and fading. By controlling the rate of the random number selection, the amount of spread and fade may be bordered.

The techniques discussed above have been utilized to generate the narrowband noise. Obviously some of the effects have impact on the system design. For an example, as the sine waves must be any frequency, ranging from a very low frequency to higher frequencies, there can be no further filtering of the output of the narrowband audio generator. The only filter allowed will be a final system filter limiting the bandwidth to that of interest to the sonar being simulated. This, in turn, sets the number of points that must be used per cycle to ensure that the harmonic content in the band of interest is low by placing the higher amplitude harmonics outside of the band of interest.

Another consideration is the resolution required on the lines. Consider, for example, that lines, controllable in 0.1 Hz, are desired; this dictates the number of fractional bits that must be carried with the count word. A potential problem existed previously, because a non-integer number of samples per cycle is used, with the possible net effect of creating subharmonics. If this were so, then the effect would show up on spectrum analyzers and cause operator distraction. A computer analysis, however, definitely establishes that there is no subharmonic generation.

System considerations must take into account the required step size to move the undesired harmonics out of the range of interest, thus setting

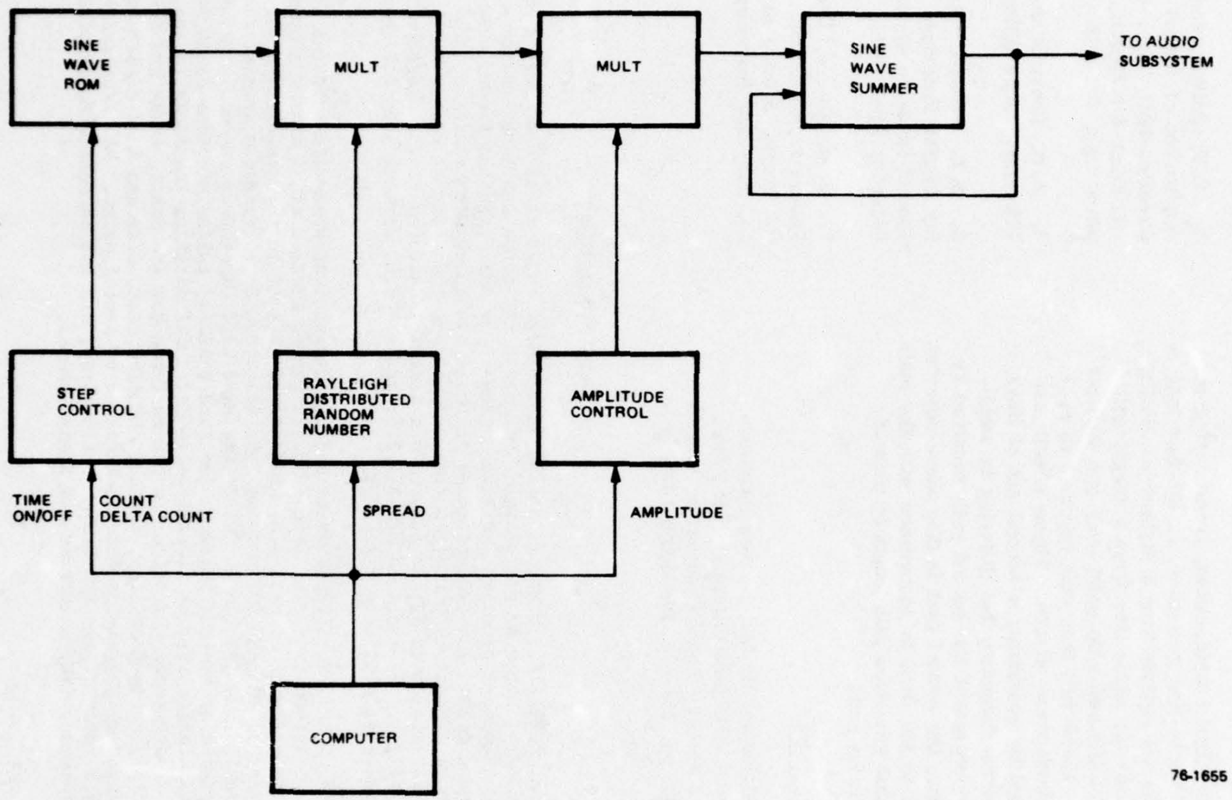

Figure 3. Narrowband Generator Block Diagram

the number of samples per second required. The controllable amplitude range and the desired amplitude steps will, in turn, establish the number of bits required to obtain range.

One final consideration, transcending that of the simple line generator, is the fact that in the undersea environment a distinct possibility exists that the same line from a target will arrive at the own ship point over two vertical paths. These will then sum together to produce interference effects. These effects are simulated by generating a second set of lines, at the same frequency but differing in amplitude, to represent the second path received by the sonar; the second path is then phase-adjusted relative to the first in accordance with the math model that generates path length or time of travel on the path.

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A SYSTEM ORIENTED BENCHMARK FOR TRAINING SIMULATORS

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1. INTRODUCTION

An important task in the development of training simulators is determining the computing system which is adequate for the computational task required. The definition of the simulator computational system as well as ensuring its adequacy has been rendered more difficult by the increasing complexity of available computer systems, the ever changing computer systems market and the growing sophistication of the training simulator computation requirement.

Several selection tools have been previously available, but are generally CPU rather than system oriented. Since these computer selection tools do not address simulation processing parameters, they are of limited utility in selecting computer systems for this application. Hence, the Air Force is striving to develop a computational system selection technique which is based on training simulator requirements and is flexible enough to be used in the various types of computational systems presently found in training simulators. The tool required is a system benchmark which will measure the total capability of the computational systems.

2. BACKGROUND

The digital computation systems originally provided for training simulators were single CPU computer systems. These computers were programmed in assembly language and required relatively slow responses. By relatively slow, we refer to a comparison with the modern training simulator and the necessity to drive an advanced visual system.

The design for these computational systems was initially based on deriving, from the functional requirements of the system, the high-level flow chart for the program and estimating the numbers and types of instructions required. Calculation of a data base was then added to determine the memory requirements of the system, the speed being defined and verified by the estimated calculational requirements.

As design became somewhat more advanced, some scientific mixes of instructions were defined for the typical calculational program, such as the classical gibson mix, and the adequacy of the computational power was determined by measuring the capability of a CPU to handle the assumedly representative instructions repertoire.

Historically, hardware has been evaluated. Williams[1], as well as Stimler and Bruns[2], gives examples of techniques for calculating computer performance and selecting an appropriate machine.

Lucas[3] lists and describes the various techniques used for performance evaluation:

Timings
Mixes
Kernels
Models
Benchmarks
Synthetic Programs
Simulation

He concludes that simulation is the optimum technique, but recognizes disadvantages, including cost. Boyse and Warn,[4] as well as many others, have described computer modeling for performance prediction. They make the comment, which may be self-evident, but is important, "Modeling can be useful, but any model can easily produce invalid results if its input data or assumptions are incorrect."

Progress was made as more experience was gained by being able to use analogy from one system to another. Based on previous experience, it was possible to get a gross estimate of the numbers of instructions and data required for various simulator functions by using approximations from one simulator system to the next. Similarly some benchmarks were derived based on the actual software of previous simulators. The benchmarks presently available give some indication of comparative machine power, but they are necessarily limited in the amount of functions they can replicate and are in general limited to single CPU investigations.

With the passage of time, the aircraft for which the Air Force must train its pilots have become increasingly complex and the training simulator has followed them in sophistication. This increased sophistication is brought about not only by the increased complexity of the aircraft, e.g., multiple on-board computers, but has also been brought about by the desire to provide more sophisticated training capability.

The expanded use of software to achieve these levels of simulation together with a significant increase in computer performance capabilities has facilitated use of FORTRAN and commercial software. Use of these software tools enhances software supportability. Simultaneously, the increased complexity of the simulation job has brought about the need for multiple CPU computational systems which utilize shared memory, inter-computer channels and sophisticated input/output devices for their recording as well as occasional overlays.

Computer systems design and verification, once performed by manual computations augmented by heavy doses of intuition, can no longer be handled satisfactorily without an automated tool which provides the ability to judge system capability objectively. Note, we talk about systems capability, not computer or CPU capability, since much more than the capability of the CPU is involved. The computational system must be judged on its practical capability, throughput capability, configurational capability, as well as the important software tools such as the operating system, compiler and utilities which form an important part of the total computational systems.

Lucas emphasizes the importance of the programming system stating, "Because the programming system is an integral part of modern computers, the evaluation process must now consider software as well as hardware in assessing performance."

Thus, it is no longer sufficient to attempt to estimate the capacity of a data processing system in terms of a number of average instructions or operations. It has become essential to have a tool which measures all the critical system parameters and which is flexible enough to put appropriate emphasis on those which are most important for a specific training simulator. This leads to the idea of a system oriented training simulator benchmark.

So called "natural" benchmarks also pose some problems. Keller and Denham[5] comment on the difficulty of running a benchmark on all systems, exactly as configured in proposals. This, however, is required if valid results are to be obtained.

An implication of the "system benchmark" concept is provided in Joslin,[6] who also defines an Application Benchmark (Problem) to be "a routine to be run on several different computer configurations to obtain comparative throughput performance figures regarding the abilities of the various configurations to handle the specific application." This implies that the specific routine to be executed is an integral part of the benchmark problem.

As we are interested in allowing varying approaches to a specific functional requirement, we feel that it is more appropriate to start from the functional definition of the set of tasks to be performed. The specific processing design is assumed to be dependent upon the computational system configuration to be used.

The advantages of using totally synthetic programs rather than natural programs are discussed in Oliver, et al.[7] Primary advantages are portability and limitation of processing time. A disadvantage is the time and cost required to prepare programs.

We intend to circumvent these difficulties by providing synthetic, but representative, operational designs, implemented primarily by consistent blocks of FORTRAN code. The constraint of FORTRAN is imposed because of the de facto standardization of FORTRAN as a training simulator language as previously discussed by Babel.[8]

3. MEASUREMENT

The system benchmark must measure both system parameters and machine parameters and must weight these parameters such that the results indicate the capability of the system to do the entire job. System parameters are those system features which impact the entire computational system, not specifically the computational capability of CPU. The system parameters include:

- Operating System Capability
- Operating System Efficiency
- Fortran Efficiency (compiled object code)
- I/O Capability
- Multiprocessing Capability
- Systems Extendability

Naturally, the most important part of the benchmark is to measure the actual computational power of the system. This must be measured across more than one CPU if a multi-CPU system is envisioned. For example, a distributed CPU system may indeed have more computational power than that provided by a single, larger CPU. However, the power of the distributed system does not increase linearly and the benchmark must measure not only the power of the single CPU, but the extent to which processing power is increased by additional CPUs.

Thus, the benchmark must examine such traditional parameters as handling of specific data types, arithmetic capabilities (particularly floating point), general

functional capabilities and logical functional capabilities. It must also be capable of examining such nonclassical capabilities as the interference between CPUs operating on a shared memory, the possibility for distributing computational power, the effect of inter-computer communication, both on computational power and I/O capacity. Finally, the benchmark must be able to assess the capability of the system to perform all these functions in the FORTRAN environment, with respect to the effect on both processing time, memory requirements, and codeability with proposed extensions.

Since many of the parameters which are being measured are intimate features of the specific systems being investigated, it may not be possible to code a particular benchmark program and execute it on all machines. FORTRAN extensions for different systems are different, operating systems have different requirements, and machine-machine communication requirements are different.

It is proposed, therefore, to develop certain blocks of code from representative simulator systems. These blocks of code will be FORTRAN coded and will represent typical simulation tasks. In addition, the functions to be performed by the system will be specified by means of high-level logic descriptions.

An example of the type of functional benchmark design under consideration is shown in block form in figure 1. Program A operates on $input_A$ to produce $data_A$; program B operates on $input_B$ to produce $data_B$. Program C operates on dataA and $data_B$ to produce $output_C$; $program_D$ operates on $data_B$ to produce $output_D$. As a further constraint, the larger of output C or D will be used for the next computation.

Depending on the time frame in which $output_C$ and $output_D$ are required, as well as the available computational speed, the sequence shown in figure 2 might be sufficient. This, obviously, is a single CPU solution. However, in a compressed time frame, one might execute programs A and C in one machine, while executing programs B and D in another. This would yield an executing configuration very similar to figure 1 itself.

A good benchmark should be able to determine whether either proposed configuration can handle the assumed processing load in the context of operational programs, FORTRAN coding, commercial system software and a superimposed environment (interrupts, I/O, etc.). Therefore, it is important to avoid specifying a configurational solution in the specification or the problem.

In order to avoid specifying the sequential or parallel performance of various functions, standard flow charts, with their inherently sequential flavor, will not be used to define benchmark requirements. The type of documentation under consideration would be similar to directed flowgraphs. This will allow the potential parallelism of the problem to be presented.

A directed flowgraph for the process previously described is presented in figure 3. The functional parallelism is evident and the association with a single machine/multiple machine implementation has been removed, thus divorcing the functional requirement from the implementation design.

A brief definition of the symbols used in this description follows. The description is taken from Rubey,[9] which provides more detailed information.

A directed flowgraph represents a computing machine in which the operations are represented by the nodes of the graph, and the transmission and storage of data and control information is represented by connecting links. Control links are represented by lines with open arrow heads; data links have solid arrow heads.

Several classes of nodes are used, two of which are shown in figure 4. Operator nodes represent a function of one or more inputs. Data operators have output connectors, all of which are data. For example, task nodes perform some operation on the data conveyed by the input data links and make the result available on output data links. Task nodes may also have input control links which affect the execution of the node, but do not affect the value produced if the execution proceeds.

A specific operator node which is used in the example of figure 3 is the identity node, labeled "I." This is a data node which transmits its input data value to all data output links with no change. Its utility comes from its use with control links.

The selector node is the means by which alternate sequences of operations may be executed, based on the value or status of some data. Selector nodes have at least one data input link, and always have two control output links. The selector has associated with it a predicate B, which is applied to the data on the data input links. If the resulting value is TRUE, then the "+" control output is ENABLED and the "-" control output is DISABLED. If the result is FALSE, then the converse link status results.

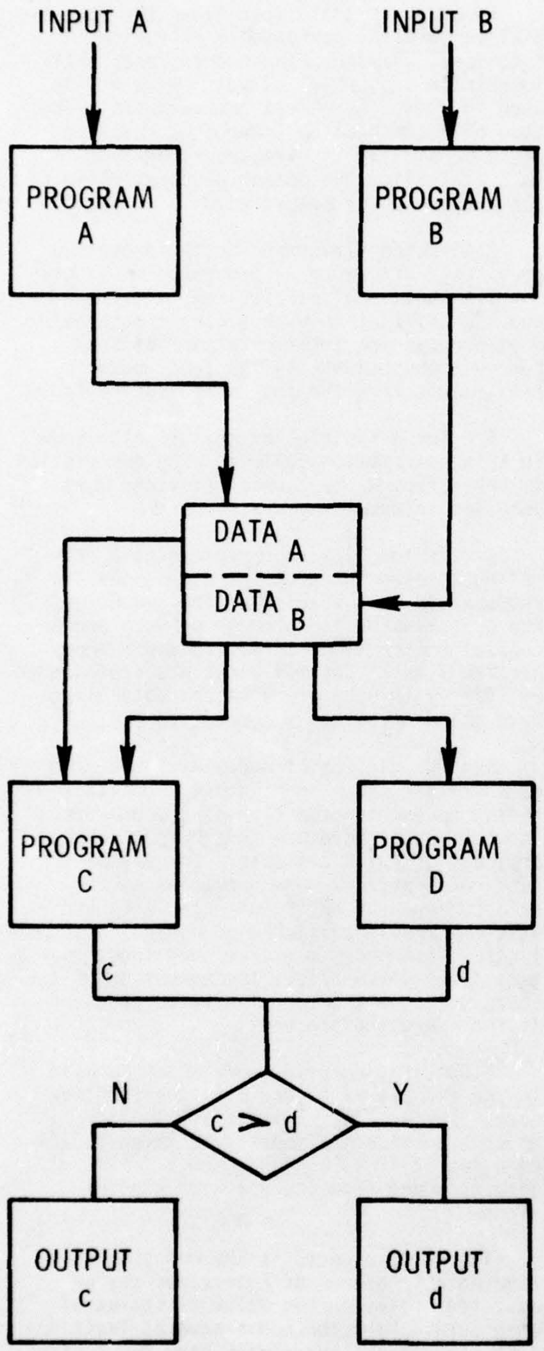

Figure 1. Required Data Flow

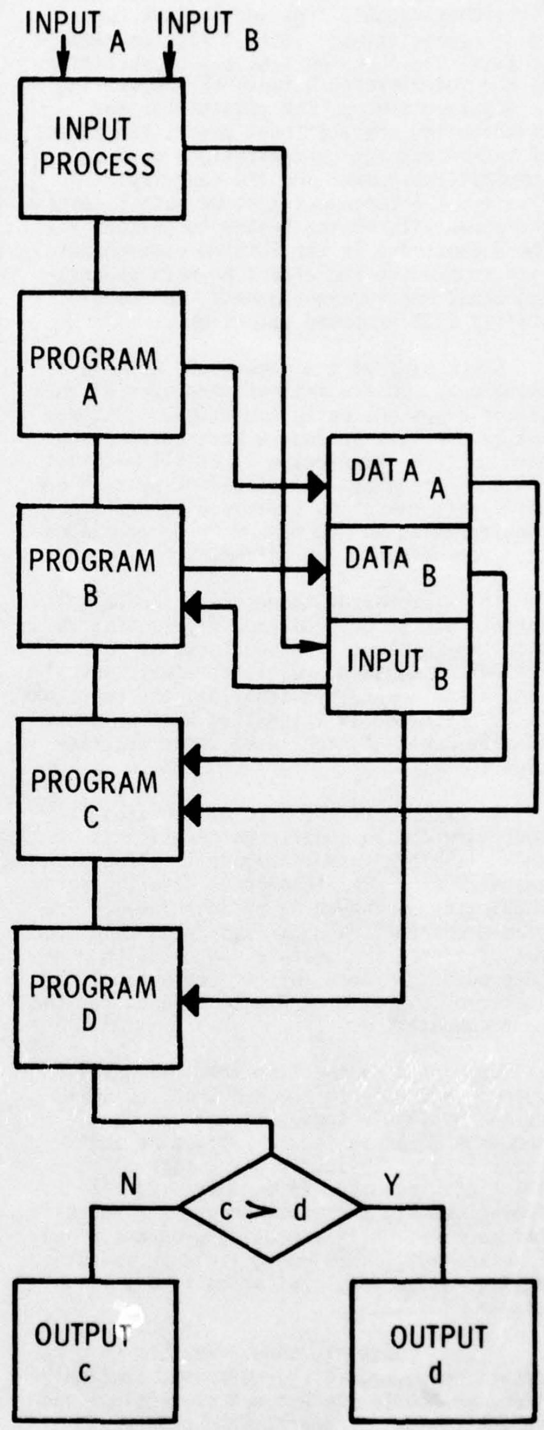

Figure 2. Sequential Data Flow

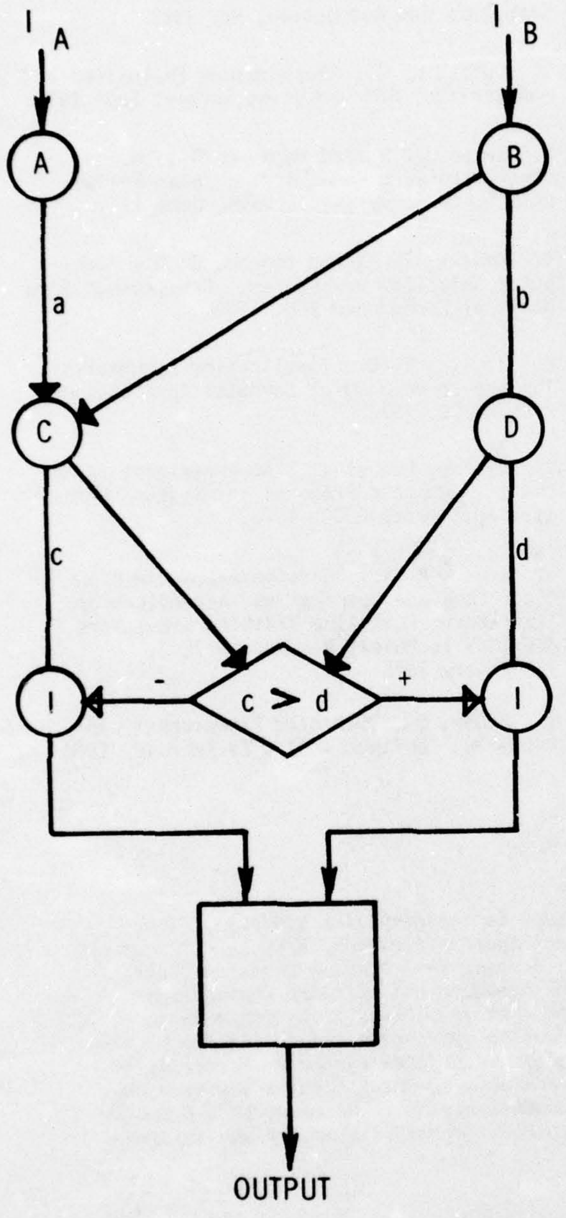

Figure 3. Flowgraph for Task Processing

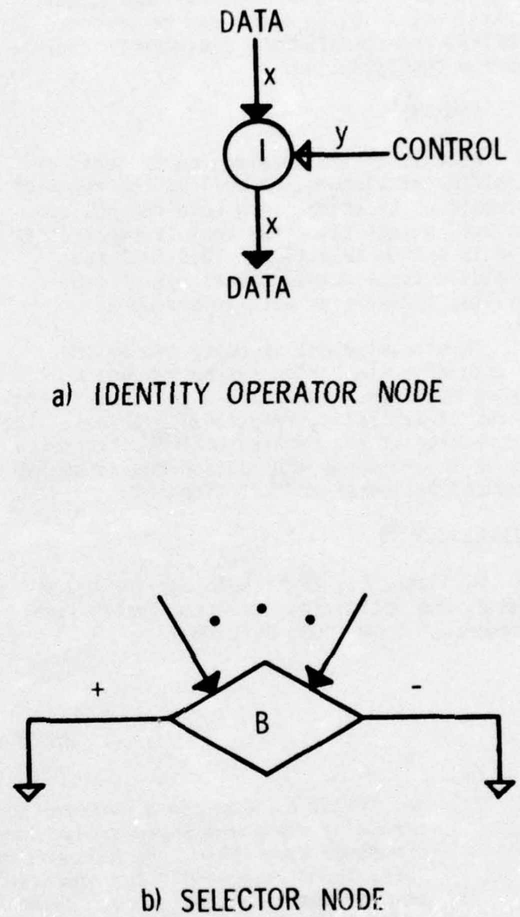

Figure 4. Sample Flowgraph Nodes

Considering figure 3, we see that the functions delineated by the left and right hand processing chains now appear independent from a processing point of view. They can be implemented in whatever fashion is most appropriate for the particular proposed configuration. The code used for the actual operations A, B, C, and D can be prepared in FORTRAN and compiled and executed regardless of the configuration.

4. SUMMARY

Because of the complex requirements of training simulators, as well as the range of techniques by which these requirements can be met, a semi-automated tool is required to aid in system selection. This tool must evaluate total computational system capability; software as well as hardware.

This requirement is being met by the design of a simulation system benchmark based on natural code blocks configured into a set of synthetic, functional problems. The expression of the problem will be structured so as to avoid any implication regarding the implementation of the solution.

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INCORPORATION OF DIGITAL AVIONICS SYSTEMS
IN THE B-1 TRAINING SIMULATOR

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INTRODUCTION

The B-1, which is intended to replace the B-52 in the Strategic Air Command (SAC) inventory, has several simulator requirements, ranging from study carrels to full mission simulators. The aircraft has a sophisticated avionics package, similar to that in the FB-111. It controls the navigation, weapon delivery and defensive functions for the aircraft. It utilizes a number of analog and digital computing devices whose functions have an impact on the simulator. A detailed analysis of the avionics system was accomplished in order to identify the problems that may be encountered in fulfilling the avionics function requirements for the crew training simulator and indicate which approach(es) to implementing the avionics functions would be most cost effective over the life cycle of the B-1 simulator. There are several simulator requirements which have no equivalents in the aircraft. One such requirement is the capability to freeze the mission, usually with the intent to reset the simulated aircraft to another position, or to instruct the crew concerning a portion of the mission without their having to concentrate on aircraft status. Another such requirement is parameter freeze, i.e., the ability to freeze certain parameters such as fuel status, pitch, altitude, etc. This allows the instructor to make a task easier by freezing one or more parameters so that the crew can concentrate on other tasks. These requirements represent a definite challenge to the implementation of avionics functions in the simulator.

AIRCRAFT OVERVIEW

The B-1 is a long range, supersonic, swing-wing bomber. Its mission includes tanker rendezvous, low level penetration at high subsonic speeds and the weapon delivery of high energy conventional stores, nuclear gravity stores, and SRAMs. The B-1 has a crew of four: pilot, copilot, Offensive Systems Operator (OSO), and Defensive Systems Operator (DSO). The OSO and DSO are physically located separately from the pilot/copilot in an aft station. There are presently provisions for two instructors, one in the cockpit and one in the aft station.

Pilot/Copilot Station

The most striking departure from previous aircraft instrumentations is the Vertical Situation Display (VSD), essentially an electronic Attitude Direction Indicator (ADI). It utilizes a computer driven CRT, which can also be used to display Forward Looking Infrared (FLIR) information. In production models this CRT may also be used to provide offensive station data, such as weapon status, to the pilot. Although the traditional dial-type instruments are still present (particularly in the backup instruments) much of the pilot/copilot information is provided on vertical tape type instruments and some in digital format (such as airspeed, mach number, and altitude).

The B-1 has a Terrain Following Radar (TFR) which has a display between the pilot and copilot. This system has two analog computers which are dual redundant and can operate in a manual or automatic mode.

In the first three prototype aircraft, the escape system consists of a crew module; however, in the production models this will be replaced by individual ejection seats. This change has necessitated some redesign of the instrument panels, particularly in the aft station. This may delay development of the aft station in the simulator.

The B-1 is also equipped with an automatic flight control system (AFCS) which provides a variety of pitch and roll, automatic guidance and automatic throttle control. This system uses two analog computers in dual redundant mode.

Aft Station

While Rockwell International has the airframe responsibility, Boeing (Seattle) and AIL share responsibility for the aft station, with Boeing being the overall avionics system integration contractor. The Offensive Station utilizes a Forward Looking Radar (FLR) for navigation and weapon delivery and a Forward Looking Infrared System (FLIR) for use in a nuclear environment. The FLIR presentation appears on a multi-function display (MFD) which is physically located above the FLR display. This display can also

be used as an alphanumeric display (AND) in conjunction with the other three CRTs. In the normal mode twin ANDs are used to display navigation/weapon delivery information, while another AND is used in conjunction with the integrated keyboard (IKB) to select different options using the Offensive Flight Software (OFS) logic trees. In case of failures of a CRT, any of the other three can be used to display the required information. Navigation and Stores Management System (SMS) data are displayed on the NAV and SMS panels respectively. The OSO can also steer the FLIR sensor.

The Data Entry Unit (DEU) is a cartridge tape device by which the OSO can load the avionics computers with their computer programs and mission data. He has the capability to erase classified data and to shutdown the offensive computer complex. The DSO has the same capability over the defensive computers. Both operators have access to the Central Integrated Test System (CITS) Control and Display (CCD) panel, and a few flight instruments.

The DSO has an IKB and CRT which are identical to the ones in the offensive station, except that navigation/weapon delivery functions are automatically locked out (likewise the OSO cannot enter any DSO functions from his IKB). The DSO has two electronic display units (EDU) which can be used to display the threat environment in panoramic or situational format. The information displayed on the EDUs is entirely computer generated. Aural warning is provided for immediate threats such as a detected missile launch. Additionally, the DSO has the option to request reconstituted audio for any detected emitter.

The defensive system is basically an automatic system, but the DSO has the option to override the system and change jammer power, threat priorities, etc. In the production aircraft, the DSO will also have control over expendable ECM (flares and chaff) and possibly a tail warning system.

ON-BOARD COMPUTER SYSTEMS SIMULATION ALTERNATIVES

The presence of digital processors in the aircraft presents a challenge in the development and support of training simulators, particularly if the processors are software programmable. The question of providing the best way of simulating systems which utilize such processors is a vital one, since it has a great impact on development risk, performance, facility for change, and on initial and life cycle costs of the simulator. It is usually not advantageous to use aircraft equipment in the simulator because of the high cost of such equipment and because the simulator operates in a simulated instead of a "real-world" environment. It is neither necessary nor cost-effective, for example, to use an aircraft operable UHF transceiver, since any ground communication is usually handled by the instructor; hence, an inexpensive intercom set is sufficient. Likewise, it probably is impractical to use the nuclear-hardened devices used in the aircraft, since the simulator will not encounter an environment which requires such protection.

With programmable digital devices an additional consideration must be made, i.e., what kind of a change activity is expected over the life cycle of the aircraft (and consequently of the simulator)? Devices in which the program is expected to change frequently are usually core memory driven, while devices in which the software change activity is low frequently use Programmable Read Only Memories (PROMs), which are more rugged than core memory but are also more expensive. This limits their use in the simulator.

There are several alternative to simulating programmable digital devices. The following paragraphs will cover the approaches considered as candidates in a training simulator application.

Aircraft Hardware

In this approach the actual On-Board Computers (OBC) are used in the simulator with the aircraft Operational Flight Program (OFP). These OBCs may be softer (non-hardened) versions of the aircraft computer using non-mil spec parts, but still being functionally identical to the aircraft computer. The intent of this approach is to obtain a hands-off update capability for the simulator. The OFP support facility for the aircraft would send a tape, which is identical to the aircraft tape, to the simulator support team whenever the OFP is modified. Theoretically then, all that would be necessary to update the simulator would be to read the new tape into the OBC.

Advantages of Aircraft Hardware: Rapid OFP update for all software-only changes can be achieved, as well as one-to-one correspondence functionally with the OBC, thereby maximizing realism of signal stimuli and response to inputs. Also, the aircraft OFP is exercised much more in the simulator than in the actual aircraft, thus giving the possibility of finding bugs in the OFP on the ground which may not be found in the aircraft. This, however, does not necessarily improve the training environment.

Disadvantages of Aircraft Hardware: High recurring hardware costs are incurred

and hardware life-cycle costs may be high also, since any aircraft computer change will have to be accomplished in the simulator. The interface between the aircraft computer and its environment in the simulator must be designed one-to-one, i.e., signals must be represented exactly (timing, amplitudes, etc.) as in the aircraft. This interface is complex and expensive. Simulator peculiar functions, such as freeze, may be difficult to implement, since the simulator must use the unmodified OFP. Particularly, parameter freeze is difficult to implement. One suggested method is to include simulator peculiar functions in the aircraft OFP. This would eliminate one of the advantages of simulation, i.e., the flexibility to implement any training requirements independent of the aircraft design implementation. Additionally, any future trainer peculiar requirements may require further OFP modifications. This would increase the size of the aircraft OFP without attendant benefits to the flying mission and may preclude mission essential changes. Another problem would arise if a new OFP change comes in and it does not play in the simulator. The fault may be in the OFP itself, in the simulator, or in the interface, and may be difficult to resolve since the OFP support team is not knowledgeable in the detailed design of the simulator, and the simulator support team is not necessarily knowledgeable in the details of OFP development. Close coordination of these two software support teams would lessen the problem but would not eliminate it entirely.

Hardware Emulator

The emulator approach requires a microprogrammable general purpose (GP) computer for each aircraft OBC that is being emulated. The internal structure of the GP computer is changed through microcode to allow it to accept the instruction set of the OBC. This requires a detailed knowledge of the internal workings of the aircraft computer that is being emulated, to insure that the emulator internally looks exactly like the OBC. With this approach, the actual aircraft OFP is directly loaded into the emulator and the OFP "thinks" it is executing in the actual aircraft computer.

Advantages of a Hardware Emulator: Because the emulator uses a GP computer, it is much easier to integrate into the simulator than the actual OBC. Interface problems are minimized because of commercially available peripherals. This approach has the same advantages as the OBC approach of rapid OFP update and simulator exercise of OFP software, while the hardware cost is less because a less expensive GP computer is used.

Disadvantages of a Hardware Emulator: The emulator has all the disadvantages of the aircraft hardware approach, except as stated above. Additionally, the GP computer must be of higher performance than the OBC it emulates, and a detailed description of its internal architecture must be available.

Software Translator

In this approach a computer program is designed to accept as input a set of OFP instructions and provide as output a set of computer program instructions which, when executed in the simulator computer, accomplish the "same" performance as the actual aircraft OFP. The translation process is usually accomplished off-line and may require several passes before an executable code is generated. The translator can use the aircraft programs and media, but must operate on the OFP before it can be used in the simulator.

Advantages of a Software Translator: Development costs are nonrecurring and hardware costs are minimized. Aircraft OFP and media can be used and updates can be accomplished relatively quickly.

Disadvantages of a Software Translator: High level organic support capability may be required to resolve aircraft OFP coding not recognized by the translator, including programmer tricks which take advantage of the hardware for which the OFP was written. There is no guarantee that every tape change will work in the simulator since verification of the translator is very difficult. Development of the translator must be considered a high risk item, both in the technical and cost area.

Cross Compiler

In the past, weight and time constraints had made it necessary for the OFP to be written in assembly language. This made the OFP very efficient as far as core and CPU time was concerned, but it was hard to read and to modify. With the advance of hardware technology, it became feasible to write the OFP in High Order Languages (HOL), such as Fortran or Jovial, which are easier to read and allow easier code modification. The usual procedure is to compile and assemble the HOL program on a large ground-based computer (such as an IBM 370) and execute the resultant machine code in the aircraft computer. It would be feasible to design

another cross compiler which would take the same HOL program and process it to obtain a program which can be executed in the simulator computer. Thus the aircraft OFP would be executed in the simulator without the use of aircraft hardware.

Advantages of a Cross Compiler: Development costs and technical risks are minimized because of extensive industry experience in compiler development. The aircraft OFP in HOL format can be used (allowing exercise of aircraft software in the simulator) and relatively quick updates of OFP changes can be accomplished.

Disadvantages of a Cross Compiler: If the OFP is not 100% in HOL and/or changes are made after the compilation process and before the OFP is finalized, changes may still have to be made to the simulator OFP to obtain the same effect as in the aircraft. This would require a software maintenance team; however, as with the functional simulation approach, such a team is required for simulator software support anyway, and the use of a cross compiler would give the team a better handle on the problem than would, for instance, a translator because of the greater visibility of HOL over assembly code.

A problem may still arise with this approach in case of programming tricks (although they are less likely to be found in HOL than in assembly language programming). Another possible problem may arise in implementing training requirements such as freeze and reset; however, these could probably be implemented by additional software modules. If the OFP uses internal clocks, the timing of which are system dependent, the program may not execute exactly the same as in the aircraft; however, this is a poor programming practice and unlikely to occur.

Functional Simulation

A functional simulation of the OBC functions consists of computer programs developed from the OFP documentation. These programs could be designed as separate modules, communicating through a common data base, such that no special interface software is required. Control and execution of these OFP functional modules would be handled in the same manner as the other simulation modules and would be designed and modularly organized into the total Computer Program System (CPS). The usual procedure of implementing a functional simulation is for the simulator designer to analyze the documentation of the aircraft OFP and design his own software to duplicate those functions which can be observed by the crew in the simulator and are required for the training mission.

Advantages of Functional Simulation: This approach can be successfully implemented with low design risk and also offers the maximum flexibility to integrate into the total system design. Technical risks are low, due to extensive industry experience, provided the OFP functions are well documented. Instructional features, such as freeze, reset, malfunctions, etc., are readily designed into the CPS and present minimum difficulties in implementation. Any future instructional features are easily incorporated, because the simulator software is under complete control of simulator software support personnel and can be easily modified to accommodate new requirements. This approach minimizes both development time and computer equipment cost, since the software needs only to handle those functions which can be perceived and are necessary in the simulator.

Disadvantages of Functional Simulation: The accuracy (i.e. one-to-one correspondence with aircraft functions) by which the software operates will not be exactly the same as the actual OFP. However, this may not be of any consequence, since the simulator does not require the high fidelity required in the aircraft (since the training task is only concerned with what the crew can perceive, iteration rates may not need to be as high as in the aircraft, for example). Software costs may be high, since the simulator OFP will have to be developed from scratch, but this may be minimized due to the fact that there are many functions in the aircraft OFP which are not required in the simulator. Operational costs may also be high, since a team of software maintenance personnel must track all aircraft OFP changes and incorporate those changes which impact the training environment. However, the OFP is only a small part of the overall simulator CPS and there must be a software maintenance team anyway to provide organic support. Another possible disadvantage of this approach is that the simulator may lag behind the aircraft in OFP updates. Certainly, instances of this occurring can be pointed out, but the problem is more a management than an engineering one. It can be resolved if the simulator team is kept informed of future OFP changes, so that they can work on those changes which impact the simulator concurrently with the aircraft OFP team. Control of the OFP configuration is maintained by means of a Configuration Control Board (CCB) which must approve all proposed OFP changes. Notification of all CCB approved changes would allow the simulator support team adequate time to incorporate these changes. There should be no reason then for the simulator to lag behind the aircraft.

SIMULATION OF B-1 ON-BOARD SYSTEMS

Devices using ROMs or PROMs can be functionally simulated, emulated, or the actual hardware may be used. Because the program resides in hardware, neither translator nor cross compiler are viable options. With computers using core memory, all of the above options may be viable. Most of the processors used in the B-1 use PROMs. It was found that all of these devices could be best simulated functionally, either because they monitored real-world environment (such as the air data computers or the engine instruments signal converters) or because their function could be implemented in software in a more cost effective manner (such as the electrical multiplex processors, which operates on sets of Boolean logic equations). Table 1 lists several B-1 devices, their function, and the reasons for functional simulation. In addition, four major systems utilizing programmable digital processors are discussed in greater detail in the following paragraphs.

Electrical Multiplex System (EMUX)

This system provides the control of electrical power in the aircraft and provides the means of transferring data between subsystems. The B-1 has two EMUX systems. The forward avionics bay and the forward and aft weapons bays are serviced only by the left EMUX, while the central weapons bay and aft avionics radar bay are serviced only by the right EMUX. The crew compartment, the central avionics bay, and the wheel well equipment bay are serviced by both EMUX systems. Each EMUX system has two control boxes (one being primary and the other backup) which control message traffic and access data, and provide logic processing, format and distribute outputs. In addition, each side has a Central Integrated Test System (CITS) interface box. EMUX samples the status of switches, circuit breakers, and power controllers in the aircraft. It operates on a set of Boolean logic equations and issues power controller commands if the equation's logical value is true. In addition to data transfers, EMUX also does serial to discrete and discrete to serial data conversion; conducts self-tests; outputs data to CITS and accepts test commands from CITS in the ground mode. The structure of EMUX makes it convenient to

TABLE 1

SUMMARY OF B-1 DIGITAL DEVICES

Device	Function	Reasons for Using Functional Simulation
Central Air Data Computer (CADC)	Uses air pressure & temperature to calculate true airspeed, mach number, and related data.	It is mainly an A-to-D converter and is stable in design and not likely to change.
Rotation-Go-Around/ Angle-of-Attack/ Air Vehicle Limit (RGA/AOA/AVL)	Provides standardized AOA, air vehicle limits, and pitch steering information to cockpit instruments.	It is mainly an interface for cockpit instruments and is stable in design and not likely to change.
Fuel and Center of Gravity Management System (FCGMS)	Automatically maintains the CG by transferring fuel between tanks.	This device can be implemented with simpler algorithms in the simulator computer to provide crew training in its operation.
Gyro Stabilization System (GSS)	Provides heading, pitch, roll attitude, and rate-of-turn reference data.	The simulator "moves" in a simulated environment, hence there is nothing for the GSS to sense. Its output should be functionally simulated.
Engine Instruments Signal Conditioning & Distribution Unit (SCDU)	Processes engine sensor data for the cockpit engine instruments.	It is an A-to-D converter for the flight instruments and is stable in design and not likely to change.
Flight Instruments Signal Converter (FISC)	A-to-D and D-to-A conversion to interface the ACUC with various aircraft systems.	Functional simulation of this interface is simplier and less costly.
Vertical Situation Display (VSD)	Generates the real-time video display of flight parameters such as roll and pitch attitude, AOA, airspeed and altitude.	In a large simulator buy, it is more cost-effective to functionally simulate its functions and use non-aircraft parts for the display.

implement in the simulator. In the past, simulator engineers in designing the simulator had to search documentation to ascertain what effect each and every switch had on the characteristics of the aircraft, i.e., what events would the crew perceive if a switch were thrown, a button were pushed, etc.? The EMUX documentation provides the logic equations in a very simple format. Implementation of these functions should be simplified over previous simulator developments. It is not, however, necessary to physically include the EMUX system, since the simulator has no Station Logic Units (SLU), such as bombbay doors or launcher racks, to control, and data transfer will consist of core-to-core communication within the simulator host computer. Thus, only the functions of EMUX should be simulated.

Central Integrated Test System (CITS)

The CITS function is to detect faults and isolate faults to a unit, and display the fault detection/isolation information to the crew. It also records this information on a printer and maintenance recorder for post-mission debriefing and maintenance purposes (neither is accessible in flight). The CITS collects information via Data Acquisition Units (DAU), and interfaces with EMUX and the avionics complex. Crew information is displayed on the CITS control and display panel (CCD) which is situated in the aft station between the two operators. Upon a detected failure, CITS will transmit a warning message to be displayed on the CCD's Alphanumeric Display (AND) and turn on the light indicating which system failed. The crew can retrieve any previous messages and access core memory of the CITS Dedicated Computer (CDC) to obtain further information on the fault. CITS communicates with its peripherals on a CITS multiplex system (CMUX). In the simulator the aircraft malfunctions that are considered necessary for training are preprogrammed and under control of the instructor. Thus there is no need to detect faults, only to display the indication of a fault to the crew. Since the printer and recorder are not needed by the crew in the simulator, these CITS functions are not necessary. Likewise, the ground functions of CITS in which it controls EMUX are not needed since they are maintenance functions only. The C&D function, including the capability of the crew to access certain portions of core in the CDC, can be handled by functional simulation in the simulator host computer.

Avionics Control Unit Complex (ACUC)

The ACUC contains three SKC 2070 computers, two for the offensive avionics and one for the defensive avionics. The two offensive avionics computers operate in parallel, but each can be configured to assume the functions of the other in case of failure of one. Communication among the computers is via an avionics multiplex system (AMUX). In addition to private core memory, the three processors share a mass storage unit (MSU). The MSU is a drum with 400K of 32 bit words storage capacity and contains all the computer programs and mission data for the avionics computers. The ACUs are loaded via the DEU or the MSU. The Weapon Delivery Avionics Control Unit (WDACU) is loaded first. From a cold start (MSU not loaded), this is accomplished by the OSO inserting the program tape into the DEU. After the WDACU is loaded, the general navigation avionics control unit (GNACU) can be loaded either from the DEU or from the MSU. The defensive avionics control unit (DACU) can only be loaded from the MSU. The Offensive Flight Software (OFS) is executed in the GNACU and WDACU. The basic iteration rate is 16, with each 62.5 msec major frame divided into four minor frames. The functions are executed alternately during each minor frame. In the backup mode (one computer down) all functions are executed in the same computer. During each minor frame, the foreground programs are executed first. Any remaining time is devoted to background tasks (Impact Point Calculations, Kalman filters, and self-tests).

The Defensive Flight Software (DFS) is executed in the DACU in major frames (62.5 msec) only. There are presently no provisions to backup the DACU, although technically it would be feasible to have one of the offensive ACUs operate in the backup mode and have the other reconfigure itself to the DACU. Implementation of this capability would require some engineering redesign. The OFS and DFS are programmed for the greater part (by contract at least 75%) in Jovial J3B.

Radio Frequency Surveillance/Electronic Counter Measures System (RFS/ECMS)

This system uses a pre-processor avionics control unit (PACU) to process the emitter data from the antennas and control the jammers. The PACU is loaded from the MSU through the DACU. It contains the Defensive Order of Battle (DOB) and any defensive mission data that has been entered by the DSO using the IKB. The PACU processes the incoming signals and correlates their characteristics with the stored data to produce a prioritized table of threats which it transmits to the DACU. The DACU prepares this data for display on the EDUs and the aural warning system when appropriate.

The PACU uses a Litton LC4516D computer. The pre-processor flight software (PFS) is presently coded in assembler

language, but is in the process of being rewritten in Jovial J3B. A cross compiler will be used to generate the aircraft OFP. Since the simulator will not use actual antennas and jammers, the signal processing and control functions of the PACU are not needed in the simulator. What has to be incorporated in the simulator are the threat analysis and prioritization functions. In the simulator, the threat environment is known (i.e., it is a simulated environment), hence the functions of the PACU that are needed in the trainer should be functionally simulated. These functions should include the capability to change threat and jammer characteristics (PRF, power, etc.) and add new threats. An additional option exists if the cross-compiler approach is used to simulate the ACUC. In that case it may be cost effective to design a cross compiler for the PACU to incorporate its functions into the simulator. This would minimize the interface with the ACUC.

ACUC Simulation

There are several facts which must be taken into account while considering the simulation alternatives for the ACUC computers:

1. The aircraft SKC 2070 computer costs about $600K per copy in the nuclear hardened version and about $350K in the softer (non-hardened) version. It may be possible to acquire a still softer version, using non-mil spec parts, in the $100-150K range. The problem with the last approach is that we are essentially dealing with a new computer, whose performance, reliability, etc. is unknown. Additionally, one advantage of using aircraft hardware (i.e., reduced logistics problems) would be lost if non-hardened versions are used. Even the lowest cost version would still cost $300-450K per simulator for all three computers. It may be possible to eliminate one computer by operating one ACU in backup mode permanently, and this would eliminate some of the test functions, but they may not be necessary to meet the training requirements anyway. Even so, this would eliminate the capability to train crew members to operate in both modes.

Implementing trainer essential functions are difficult. Freeze, for example, could be implemented simply by initiating an interrupt stopping the real-time clock in the ACU. However, this would cause all displays to go dead, unless the information necessary for display is somehow retained outside the ACU. To implement parameter freeze requires modification of the OFP for simulator use. This means that either the simulator OFP will not be identical to the aircraft OFP, or the aircraft will have to fly with simulator peculiar functions in the OFP. Other problems include record and playback capability, auto demonstrations, crash override, and malfunction insertion and control.

2. Data concerning the internal operations of the SKC 2070 computer are company proprietary. This will make it difficult to design an emulator using a microprogrammable GP computer which reflects the structure of the OBC exactly. There is therefore no guarantee that a change in the aircraft OFP will have the same effect in the simulator and some simulator peculiar OFP support activity may be required with each tape release. As with the actual hardware approach, the same situation exists concerning simulator peculiar functions with the same problems of having either two different OFPs (one for the aircraft and one for the simulator) or having simulator peculiar functions in the aircraft OFP.

If this approach is used, it would be very cost effective to use the same microprogrammable GP computer for the simulator host computer(s) to allow commonality of equipment and ease the maintenance function. This would limit the choice of simulator computers to 32 bit microprogrammable GP processors. An indepth study of the SKC 2070 and available GP computers will be required to determine which computers are likely candidates for an emulator approach.

3. The present method of preparing the aircraft program tape requires the use of a cross compiler (this is also true of the pre-processor flight software, which was covered in the previous section). The design and cost risks of a cross compiler to accommodate the simulator computer would be low. The software is organized such that all programs are either in Jovial J3B or in assembler language (no in-line coding is allowed). This would make it easier to accomplish changes to the program. Simulator functions peculiar to the training environment could be inserted as additional code and new requirements could be implemented without modification of the aircraft OFP. The update capability is not as good as with the previous two approaches, since with each new tape release at least some analysis and possibly recoding will have to be done to obtain a simulator OFP. However, this approach gives much greater visibility of the total system and any bugs can be fixed more easily than with the hardware or emulator approach.

4. The translative approach has all the disadvantages of the cross-compiler approach, i.e., the translator requires off-line processing to produce a simulator OFP, including engineering analysis and computer run time. In addition, any code change would

have to be done at the assembler or machine language level. This removes the advantage of increased visibility.

5. From a development standpoint, functional simulation of the avionics has the lowest technical risk. This approach minimizes the total software and hardware, since the designer can eliminate all functions which are necessary in the aircraft, but have no equivalent function in the simulator. This is particularly true in the B-1 where much of the software is concerned with testing, statistical computations (Kalman filters), and control and display (C&D) - all of which are either unnecessary in the simulator or, as in the case of C&D, can be done more efficiently in a GP computer. This approach will require that OFP change specifications be made available as early as possible to allow simulator software support teams to keep the simulator OFP up-to-date with the aircraft.

6. There may be other approaches, including combinations of the above; however, they have not been proven in the training simulator environment.

CONCLUSIONS

All analog computers and all digital processors, with the exception of the three computers in the ACUC (and possibly the PACU, if the cross compiler approach is used) should be functionally simulated. Two approaches to implementing the ACUC computers are considered more cost effective over the life-cycle of the B-1 simulator than the other approaches. The approach which presently appears to be the better of the two is functional simulation. The following reasons are given in support of this conclusion:

1. Low risk. This approach has been implemented on many training simulators and it is a proven and reliable approach.

2. Short development time. Because of extensive industry experience with this approach, development time will be minimized. There are no unknown areas or surprises which can delay the program. This is particularly important in the case of the B-1 simulator which has a severe time constraint.

3. Low cost. The cost to rewrite the OFP functions for the simulator is nonrecurring and amounts to less than 1% of the projected total B-1 simulator cost. Even assuming that soft versions of the OBC at a reduced cost can be obtained, the hardware cost will still be several times higher than the cost of a functional simulation. This does not take into account the additional cost of the AMUX system, the cost of the interface with the simulator, contractor overhead charges for the hardware procurement, and the software cost of having to implement a more rigorous environment model if the OBC is used.

4. High flexibility. Simulator peculiar requirements such as freeze, reset, malfunctions, and parameter freeze are easily implemented. Any future requirements can be easily implemented. At the same time, the simulator OFP is not hardware dependent, i.e., if the aircraft computer is replaced or modified, the simulator OFP need only be modified if there is a change in performance that the crew can perceive. In such a case there would be no high hardware costs associated with the simulator.

5. Control of configuration is maintained by the simulator community. This may be the most important advantage of functional simulation, i.e., the simulator is not dependent upon the aircraft OFP for its training capabilities. This would not be the case if the actual hardware or an emulator were to be used, since the aircraft OFP would then have to contain the freeze, reset, etc., capabilities which are necessary for the simulator. In other words, the simulator requirements would be in direct competition with the operational requirements for time and core in the OBC, and dependent on the aircraft community for implementation.

6. Good update capability. Traditionally this approach has been accused of causing long delays in simulator updates and expensive ECPs to keep the simulator current with the aircraft. These facts may have been true in the past, but are not necessarily true today. The Tactical Air Command (TAC) has had great success with their Development Technician Team (DTT) to update all simulator software, including the OFP portions. Last year TAC rejected a suggestion to incorporate the TC-2 computer into the A-7D simulator on the grounds that they had no update problems. They felt that as long as their DTT was kept informed of future OFP changes, they could beat the aircraft in implementing a change. They also felt that the approach was too expensive, degraded their training capability, and would take too long to implement. HQ USAF/XO and AFSC concurred with TAC's position.

The recommended method of implementing OFP changes in the simulator is to require that the SAC equivalent of the DTT be kept informed of any future OFP changes and that the funding for any aircraft ECPs which affect the simulator contain funding for simulator ECPs as well. This will insure a timely update capability for the simulator OFP without requiring a high cost/high risk approach to simulating the avionics system.

The other viable approach is the cross compiler. Its cost is comparable to that of the functional approach and is much less than that of aircraft OBCs or emulators. It has a slightly higher development risk than functional simulation, since it has not been proven in a training simulator, but it would give maintenance personnel a better chance of tracking any bugs in the system which may be impossible to find with the aircraft OBC or emulator approaches. It allows some of the functional simulation options of deleting code which has no impact in the simulator or adding subroutines to take care of freeze, reset, etc. It would also allow the option of using Jovial J3B as the simulator computer language to minimize interface problems.

To take care of the non-Jovial code (the executive, I/O, etc.), the simulator contractor could write new code, or else microprogram the simulator computer to accept the instruction set of the SKC 2070. This approach is not as technically proven as the functional approach, but it is the best of the approaches which use the aircraft OFP, and thus would be the best approach if exercising the aircraft software in the simulator is required. This does not mean that the other approaches are without merit. On the contrary, with different applications and requirements, the emulator, for example, may be the best approach. But for the B-1 training simulator program, those approaches are not recommended for the reasons stated above.

A further trade-off study should be made to determine which of these two approaches is best suited for the B-1 simulator in terms of life-cycle cost and training effectiveness. It should be noted that the aircraft aft station is behind in development compared to the front station, and hence a delay of one year in production of the simulator aft station would prevent costly ECPs to keep the simulator configuration current with the aircraft. This time period can be used to accomplish the recommended study. The study should, as a minimum, address the initial development cost; the time for development; a development risk assessment; an analysis of anticipated software changes and their impact on the simulator; the update capability; the number and qualifications of software maintenance personnel required; and predicted life-cycle costs for each of the two approaches.

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AIR-TO-SURFACE FULL MISSION SIMULATION
BY THE ASUPT SYSTEM

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ABSTRACT

Air-to-surface weapons delivery is one realm of visual flight simulation which has been rather neglected until recent investigations were made by the USAF to determine the state-of-the-art in this area. As part of this investigation (Project 2235, Air-to-Ground Visual Evaluation), the Advanced Simulator for Undergraduate Pilot Training (ASUPT) system was expanded to include the additional capabilities required to perform air-to-surface weapons delivery. Evaluations of the various systems under consideration have shown the ASUPT computer image generation approach to air-to-surface visual simulation to be the most viable. This paper summarizes the engineering modifications made to the ASUPT system for Project 2235 and presents the operational capabilities of the new system configuration.

INTRODUCTION

Project 2235 arose from an urgent requirement to determine the state-of-the-art in visual air-to-surface (A/S) mission simulation. Specifically, the project supports the establishment of Required Operational Capabilities (ROC's) for the proposed A-10 and F-16 Mission Simulators. Air Staff RDQ and the Aeronautical Systems Division/Simulator Systems Program Office (ASD/SIMSPO/SD24F) of Air Force Systems Command (AFSC) felt that a study to assess visual simulation capabilities was necessary to reduce the performance and cost risks of procuring aircrew simulators which require A/S capabilities. A consortium of the Air Staff, ASD/SIMSPO and AFSC arrived at a decision, dictated to a large extent by available funds and time, to make the assessment by evaluating three systems currently in the field. These systems are the Advanced Simulator for Undergraduate Pilot Training (ASUPT) System located at Air Force Human Resources Laboratory, Flying Training Division (AFHRL/FT), Williams AFB, Arizona; the Large Amplitude Multi-Mode Aerospace Research Simulator (LAMARS) located at the Flight Dynamics Laboratory (FDL), Wright Patterson AFB, OH; and the Simulator for Air-to-Air Combat (SAAC) F-4E No. 18 combined systems located at Luke AFB, AZ. Each of these systems utilized a different approach to visual simulation: ASUPT features a Computer Image Generation (CIG), wide-angle, field-of-view (FOV) cathode ray tube (CRT) display; LAMARS, an area-of-interest (AOI) dome projection of a model board; and the SAAC, wide-angle, FOV CRT display with a cameral model AOI of the F-4E terrain model board.

AFHRL/FT became actively involved in Project 2235 on 8 July 1975 at the Test and Support Planning Meeting held at Wright Patterson AFB. A project plan was developed at this meeting to serve as a basis for all agreements among project participants and outlining the specific A/S task objectives to be evaluated. Shortly thereafter, AFHRL/FTE developed an Engineering Development Plan to define the scope of ASUPT's ability to respond to Project 2235's objectives, to establish functional task areas requiring engineering development, and to project a schedule for the ASUPT engineering development.

It was confirmed that ASUPT could provide the capability to perform all of the A/S mission requirements established in the overall Project 2235 Test and Evaluation Plan;

however, additional development was required in both hardware and software areas.

The purpose of this paper is to describe the expansion of the ASUPT system features to include A/S mission simulation and to report the operational results thereof.

General System Description. The ASUPT system consists of two T-37B simulator cockpits. Each cockpit with G-seat is mounted on a six-degree-of-freedom synergistic motion base surrounded by seven cathode ray tubes (CRT's) with special infinity optics providing a wide-angle, field-of-view (FOV) visual display. The visual scene is produced by means of a computer image generation (CIG) technique which provides a perspective two-dimensional image of an environmental model defined in three dimensional vector space and stored in computer memory. Unique characteristics of this visual system are:

1. Wide-angle, field-of-view
2. Unrestricted viewpoint position and attitude
3. Unlimited number of environmental data bases which can be modified, amended and constructed with reasonable effort and little expense
4. Large gaming area (1250nm X 1250nm)
5. Provision for an independent moving model which may take the form of lead/FAC aircraft, moving ground target, SAM, etc.

Operational A/S Requirements Provided by the Original System Configuration. The ASUPT system, designed to accommodate research in undergraduate pilot training, easily facilitates those Project 2235 scenarios encompassing UPT missions. Tasks such as takeoffs, departures, approaches, landings, aerobatics and formation flight during day, dusk, night and varying ceiling and visibility conditions are readily accomplished.

The observance and monitoring of pilot performance and aircraft maneuvers is also provided. At the various instructor-operator stations, one may survey the situation by means of duplicate instruments, closed circuit TV, CRT monitors, and graphics displays. (See Fig. 1 AIOS)

Operational A/S Requirements Necessitating Additional Development. In addition to the requirements imposed by A/S scenarios with tasks common to those in UPT, are the ones more directly related to weapons delivery. These requirements necessitated the acquisition, modification and development of both hardware and software. First, an entirely new visual data base was designed and developed to provide an appropriate environment for air-to-surface weapons delivery. A CA503

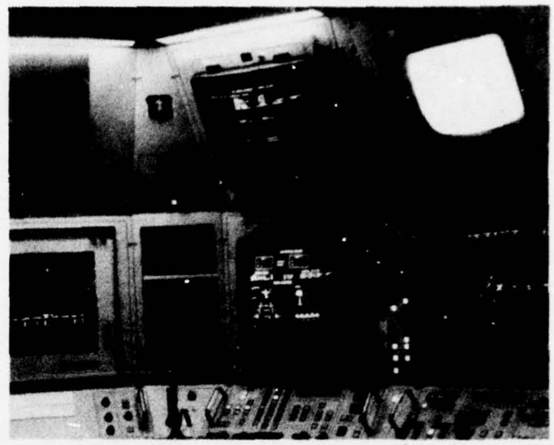

Figure 1. Advanced Instructor/Operator Station

optical gunsight for an A-37 aircraft was procured, modified, and installed in one of the two cockpits. The stick triggers were wired, activated and integrated with the simulator computer. Algorithms were developed to provide paths for the ordnance, surface-to-air missile (SAM), and moving ground target. Significant software was developed to provide visual display of ordnance ground impacts and the two graphics displays were reprogrammed to provide for delivery scoring. Also, missions utilizing the FAC/lead aircraft required a moving model visible at ranges far in excess of those for formation flight, again necessitating software program modifications. To handle the extra software in an efficient manner, 8K of computer core memory and a 24 million byte moving-head disk drive were purchased and installed.

Operational Capabilities. The environmental gaming area is a square area 36 nautical miles on a side and consists of random surface texture, an airfield, a gunnery range, and two tactical complexes. (See Fig. 2)

The airfield (see Figs. 3 and 4) is composed of a 12,000 foot fully-marked and lighted runway with numerous three-dimensional features to provide the necessary velocity and altitude cues.

The conventional gunnery range is in a baseball diamond pattern as shown in Fig. 5 and consists of two bomb circles, two skip bomb targets, and two strafe targets. Buildings scattered throughout the area, range towers, and as shown in Fig. 6, trucks in the bomb circles provide the three-dimensional cues.

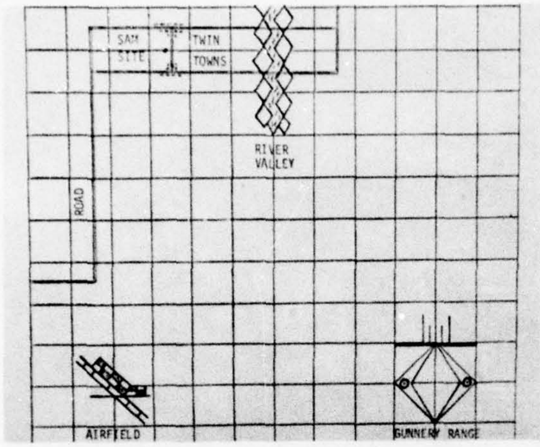

Figure 2. Environmental Gaming Area

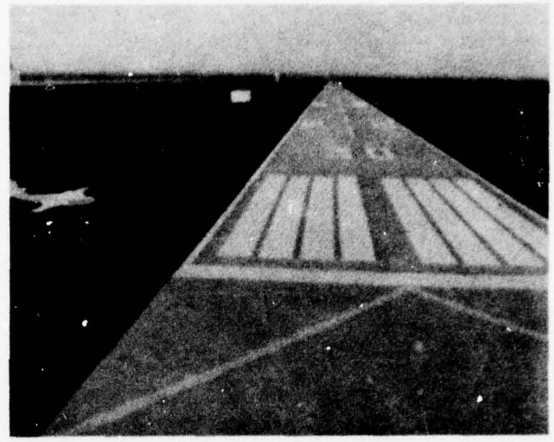

Figure 4. Threshold

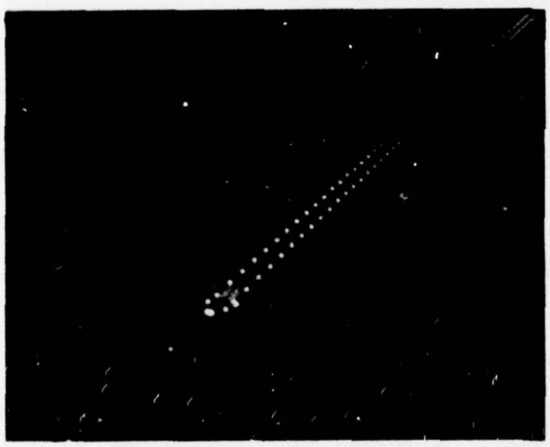

Figure 3. Airfield at Dusk

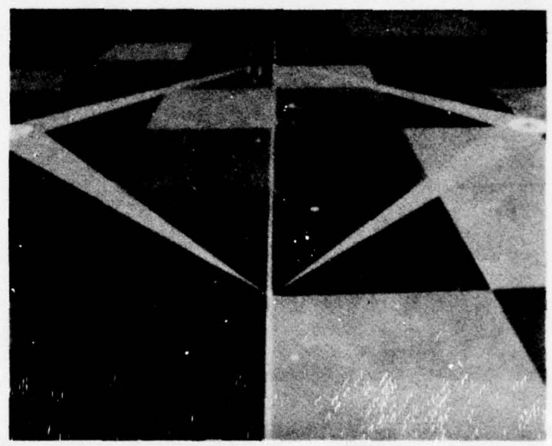

Figure 5. Gunnery Range

One of the tactical ranges consists of two small towns about four miles apart with a surface-to-air missile (SAM) site located between them. As may be seen in Fig. 7, a convoy of trucks is departing the northern town. The other tactical area is located in a river valley between two mountain ranges spanned by a pair of bridges as shown in Figs. 8 and 9. In the vicinity of one bridge is an island containing a munitions manufacturing facility. Contained in the munitions complex are a factory, ammo dump, watch towers, barracks, warehouses, dock, ship, jeeps, trucks, ambulance, tanks, antiaircraft artillery emplacements, helipad (see Fig. 10) and helicopter. The mobile features in this area change their locations during the day, dusk, and night environments.

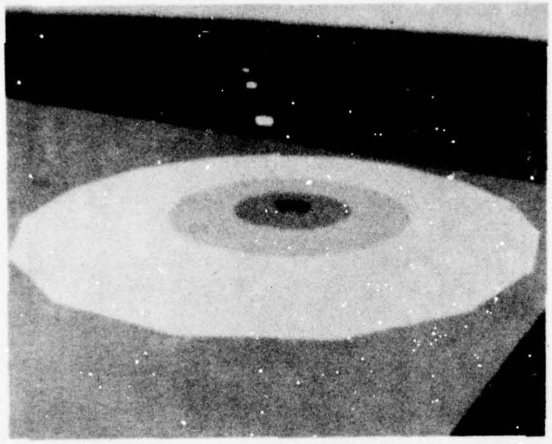

Figure 6. Bomb Circle

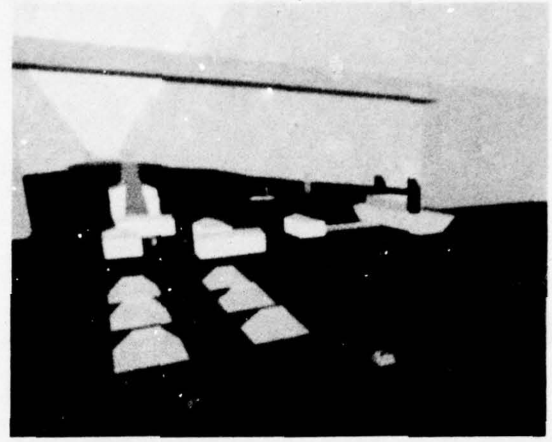

Figure 8. River Valley

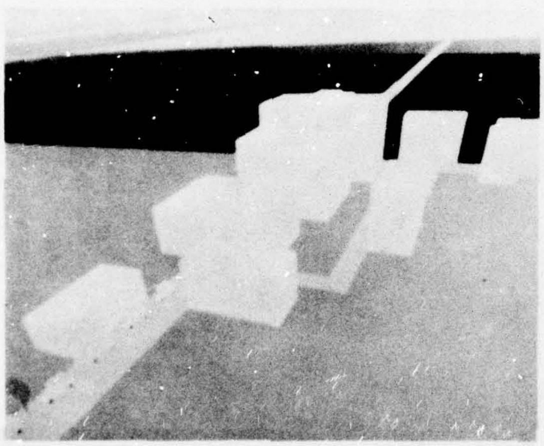

Figure 7. Truck Convoy

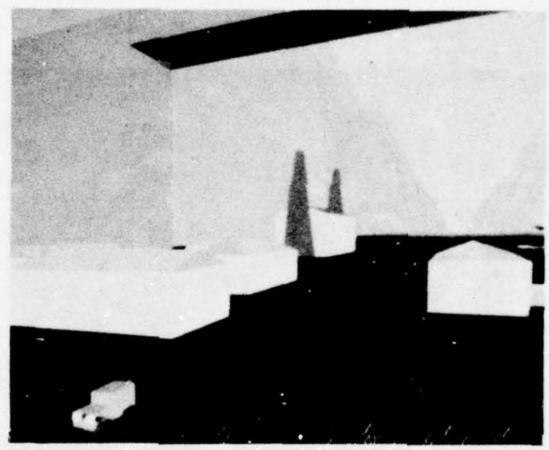

Figure 9. Munitions Complex

Within the environment, the pilot may "fire" the cannon and "drop" bombs at will. Visual ground impacts are displayed for both strafe and bomb, and when a three-dimensional feature is hit, it is deleted from the display scene. This may be observed in Fig. 11, depicting a circular white impact near the center of the bomb circle. Since a "hit" occurred, the truck has been omitted from the display scene.

Two graphics displays have been reprogrammed to provide monitoring and scoring of the A/S weapons delivery tasks for selected targets at the advanced instructor operator station (AIOS). These displays are shown at the lower left and right portions of Fig. 1. The Aircraft Delivery Parameter Display depicted in Fig. 12 presents real-time heading, altitude, airspeed, dive angle, and G-load as digital data at the top edge of the display. The remainder of this display is divided into two parts. The top half presents a side view with fixed dive angle lines (15°, 30°, 45°, 60°) radiating from target and a dynamic aircraft image moving from right to left on

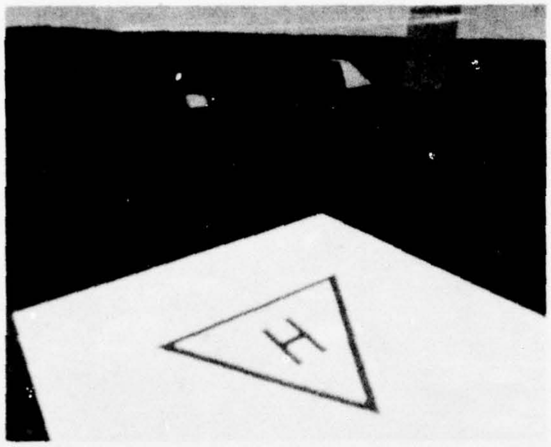

Figure 10. Helicopter

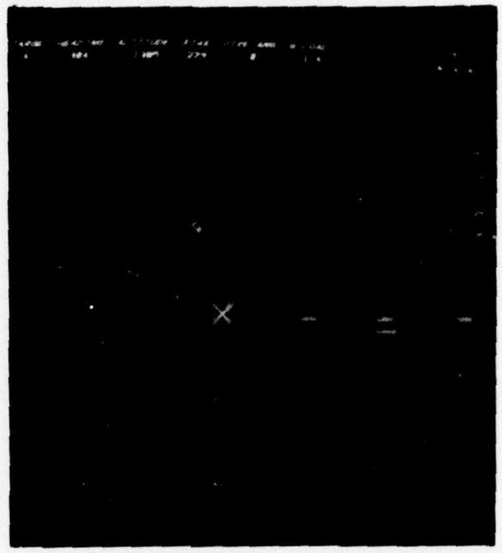

Figure 12. Aircraft Delivery Parameter Display

Figure 11. Ground Impact

the screen leaving a trail of dots in its wake as shown below the 15° dive angle radial. The bottom half is a top-down view-oriented true north also portraying a dynamic aircraft image on northerly heading with trail as shown. For strafe tasks this display also gives scoring information as a percentage of projectiles fired through the target and displays a "FOUL" if the pilot presses beyond the range foul line. (See Fig. 12). The Target-Impact Display pictured in Fig. 13 is a top-down view of the target center oriented true north with radial lines through the o'clock positions and concentric circles at 150' and 300' radius. Bomb drop impacts are indicated in their relative positions as a circle with pass number. Heading, altitude, airspeed, G-load, dive angle, and winds at time of release, in addition to radial distance of the impact from target center are accumulated for up to ten passes at the bottom of the display. A hardcopy printout of this information is also available.

With both cockpits "flying" independently, each viewing the other as the moving model, formation, mutual support and forward air control mission may be performed. An image size control program was implemented to introduce a deadband range for which the moving model perspective image remains constant. Upon reaching the limits of this range, the image's size will again commence perspective changes. This was done in an attempt to alleviate the resolution problem occurring with the aircraft at ranges in excess of 2500 feet. Fig. 14 shows the moving model of the T-37 aircraft which is used for formation flight. A more simplistic

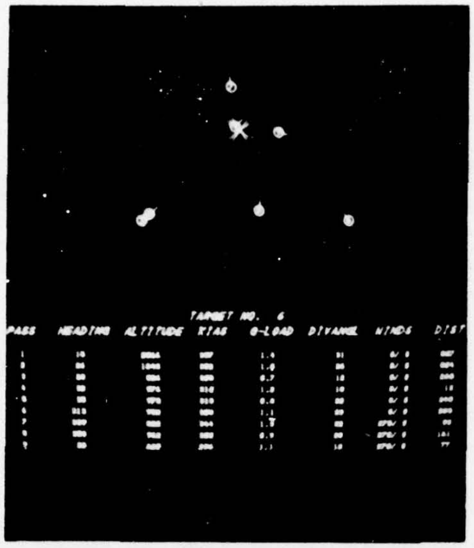

Figure 13. Target Impact Display

model is used for the lead and forward air control aircraft. Indication of a target by a forward air control aircraft is simulated by "smoke" marking of the convoy which may be turned on and off at the operator station (see Fig. 7).

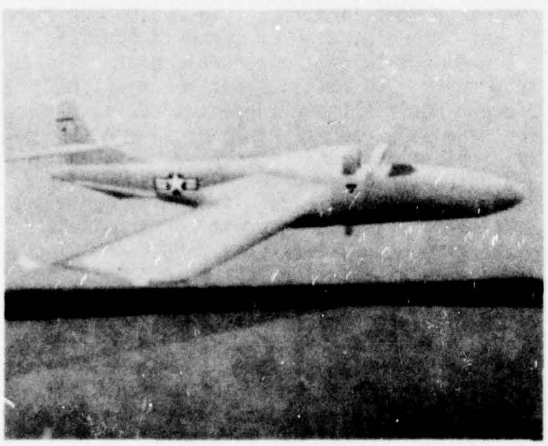

Figure 14. Formation Aircraft

Ground Fire is simulated by muzzle flashes of the antiaircraft artillery (see Fig. 15) and tanks. Aerial flak bursts also accompany the antiaircraft artillery in the vicinity of the munitions complex. A missile may be repeatedly launched from the SAM site (See Fig. 15) and will track the aircraft. In Fig. 16, the launch of the SAM is observed *through the gunsight in the simulator cockpit.* The missile may be averted if proper evasive tactics are performed in response to the missile's trajectory; otherwise a "kill" is experienced which results in a simulator crash condition.

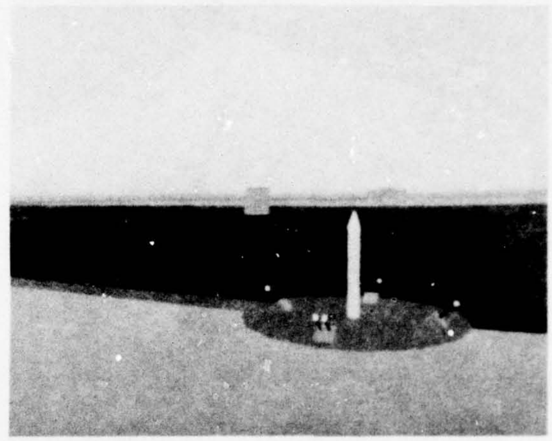

Figure 15. SAM Site

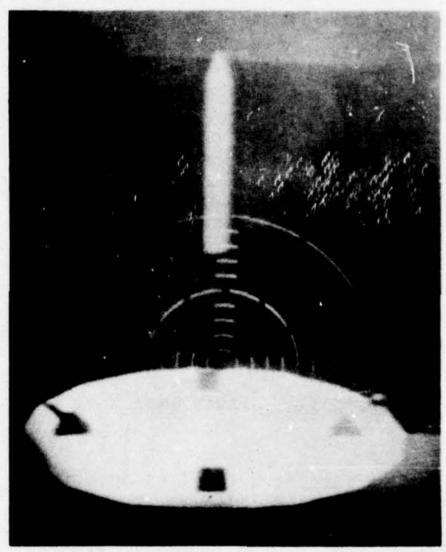

Figure 16. SAM Launch

Patrolling the SAM site and the highway between the two towns is a tank. When attacked and experiencing a "near miss," the tank will leave the road, randomly changing speed and direction to confuse the attacker. Following an appropriate interval, the tank will resume its normal patrol.

CONCLUSION

In February 1976 an evaluation of the system was performed by six Tactical Air Command fighter pilots highly experienced in air-to-surface weapons delivery. Each pilot "flew" ten mission scenarios of approximately one hour each. These scenarios were representative of all phases of A/S missions including takeoffs, landings, traffic patterns, aerobatics, formation, low level navigation, conventional range operations and deliveries and tactical operations and deliveries. The range deliveries included 10, 15, 20, 30, 45, and 60 degree bomb, and both high and low angle strafe. Tactical missions involved armed reconnaissance, locate and identify target, terrain masking, mutual support, ordnance adjustment, moving target, and FAC operations in addition to the various aforementioned delivery modes. During this interval a system reliability rate of 94% was maintained, and after a total of 60 hours system time the pilots were still enthusiastic about "flying" the simulator.

As a result of the highly successful completion of the engineering modifications and system demonstration of the ASUPT phase, Project 2235's major conclusion is that computer image generation is the most viable approach to air-to-surface full mission visual simulation.

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AN AIR TRANSPORTABLE PROGRAMMABLE AIR-TO-AIR COMBAT SIMULATOR

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INTRODUCTION

The demand for increasing use of flight simulators within the military has led to requirements for broader application and more efficient utilization.

The use of mobile simulators is by no means new to either the Air Force or Navy. Both services have used such devices effectively for years; the Air Force units being mounted in railcars and the Navy units being trailerized for highway transportation.

Current mobile simulators are limited to instrument flight simulation. The Air Force during the 1960s added visual attachments; however, this effort was unsuccessful. Recent advancements in mini-computers, microprocessors, and in computer image generation (CIG) make mobile simulators in general and visual mobile simulators in particular more feasible

Aerial combat simulation is potentially a high payoff application of mobile simulation. This paper attempts to define a minimal cost, low-risk approach to Air Transportable Programmable Air-to-Air Combat Simulators (ATPAACS).

POTENTIAL REQUIREMENT

For years, various organizations have alluded to requirements for a mobile air-to-air combat simulator. The operational advantages of such a simulator are obvious. This is especially true if one assumes that such a simulator has the flexibility to be reprogrammed to simulate various types of aircraft and if the device is capable of computer simulation of an adversary. This would allow a single cockpit device to fly one-on-one against a preprogrammed threat. Since the proportion of the flying training syllabus devoted to aerial combat may be rather small, and not warrant dedicated aerial combat simulators, the mobile simulator is very attractive. It is also highly attractive as a tool to send to the field to update pilots in the latest tactics to be used against threat aircraft. It allows a pilot to learn specific enemy tactics and the preferred countertactics to be used in one-on-one engagements. The countertactics may be changed as enemy tactics change. It can be used to provide familiarization training with the performance characteristics of threat aircraft.

GOALS

The primary goal is to define an air-to-air combat simulator which is air transportable. Ideally, it should fit into a C-130 aircraft without exceeding its weight limitation for inter-theater shipment. The simulator should have a full field of view (FOV) display (limited only by aircraft configuration) with one high resolution aircraft image input and a horizon reference. As a minimum, it should have kinesthetic cueing to include g-suit, g-seat, and buffet systems. The aerodynamic simulation should be accurate and should be easily reprogrammable to represent different aircraft. An "iron pilot" (interactive computer pilot) program to fly a reprogrammable adversary aircraft using appropriate tactics should be included. The time required to set up and tear down the simulator should not exceed eight hours and four hours respectively.

APPROACH

Various approaches have been studied including both optical and screen displays, camera/model, CIG, opaque projector image generators, one or two cockpits, and various methods of providing kinesthetic cue simulation. Several basic conclusions were reached. Large optical displays would not be practical. A dome type screen which was inflatable would best meet the display and transportability requirements. Kinesthetic cueing would include g-suit, g-seat, and buffet systems. Cockpit motion would not be practical due to siting and size constraints, setup and teardown time requirements, the impracticality of using motion inside a dome, and the problems involved with mounting a nonrigid dome on a motion base. Details of the proposed cockpit are provided below.

Cockpit. The cockpit would be simplistic with instrumentation, systems, and controls limited to those necessary for air-to-air combat. A goal would be to provide a convertible cockpit configuration with removable instruments, panels, and controls to facilitate changes to represent different aircraft configurations. Such configuration changes would be effected at depot level. Such changes could include sidearm controllers and high g seating configurations.

Kinesthetic Cue Simulation. Kinesthetic cue simulation would include an active g-suit system to provide sustained g-cues, g-seat with active lap belt to provide both onset and sustained acceleration cues, and a seat buffet system to provide additional aircraft performance cues. Other methods for providing kinesthetic cueing would be considered during the development phase of the program.

Operator/Instructor Area. An operator/instructor area would be provided which would stress use of the latest instructional aids and cathode ray tube (CRT) type terminals to provide feedback to the operator/instructor and to provide a means for the instructor to brief and debrief pilots.

Image Generation. There are several alternatives available for generating the image of the opposing aircraft. They include CIG, camera/model systems, and an opaque projector system. The CIG approach is the most flexible since the three-dimensional aircraft image is digitally stored and may be changed with software alone. This approach, however, provides the least realistic aircraft image. A camera/model system provides a more realistic image but is less flexible and less reliable. The opaque projector system would involve projecting the image from a highly illuminated gimballed model to the screen with relay optics. This simple, reliable technique provides image resolution exceeding that of the human eye but is still less flexible than CIG, requiring physical model changes with the opaque projector. One problem that must be overcome is that the low light efficiency of the system may result in a dim display.

Display. The key element in any air-to-air combat simulator is the visual display. An extremely large field of view is required. Two basic approaches to providing such a FOV have been investigated. The first approach uses an inflatable dome similar to those used to protect radar antennas. Such a dome should be at least 16 feet in diameter with a 20-foot diameter preferred. The layout in Figure 1 shows an 18-foot dome. The input to the display would be either a television or opaque projector. If the opaque projector is determined to be impractical, hardened monochrome television projectors are available which would be ideal for mobile use. The background display would be provided by a point light source projector using spherical transparencies to provide horizon, sky, and ground plane for attitude and heading reference. The second approach investigated was a combination helmet-mounted sight and a helmet-mounted display. This approach would provide an unlimited FOV for the pilot with a minimum amount of hardware. It involves feeding video information including the threat aircraft and horizon and background into the helmet display and controlling position of this imagery with positional information for the helmet sight. The disadvantages of this approach are the limited instantaneous FOV of current helmet displays and the interaction between information displayed on the helmet and the cockpit structure and instruments. Current systems have an instantaneous FOV of only 25 - 40 degrees and only input imagery to one eye. The limited FOV would require more than normal head movement by the viewer. Initial indications, at this time, are that the dome display is more practical and may be lower in cost.

Radar. Radar simulation would be limited to airborne targets which would be generated digitally using conventional techniques.

Computer. The heart of the mobile air-to-air simulator would be the computer. Currently available mini-computers are extremely compact and could readily handle the simulation required. Initial indications suggest the use of two central processors and peripherals including a teletype and at least two magnetic discs. For those computations that do not require reprogramming, such as integration, linear function interpolation, g-seat, and control loading systems, the use of microprocessors should be considered. It is anticipated that with proper shock mounting and environmental protection it would not be necessary to provide hardened computer equipment.

Simulator Enclosure. The goal of this program would be to have the simulator in two enclosures, each with maximum dimensions of 8 ft X 8 ft X 20 ft. This would allow the simulator to be transported in either a C-130 or C-141. Modifications of standard electronic shelters with built-in environmental control equipment would probably be used to insure compatibility with International Standards Organization (ISO) transportability requirements. It may be desirable to include an auxiliary power unit to assure that adequate stable power is available for the simulator. Figure 1 shows a preliminary layout of the simulator with the two enclosures butted together for operation. A wall at one end of the instructor/console section is removed prior to assembly. A section of the enclosure at the cockpit area is removable to allow inflation of the spherical dome. An air lock is included to allow the pilot to enter the cockpit enclosure with the dome inflated.

Training Considerations. To take maximum advantage of the mobile simulator concept and to provide current training, the simulator must provide training against the tactics used by threat aircraft and permit relatively rapid tactics changes. Threat aircraft performance is an important part of

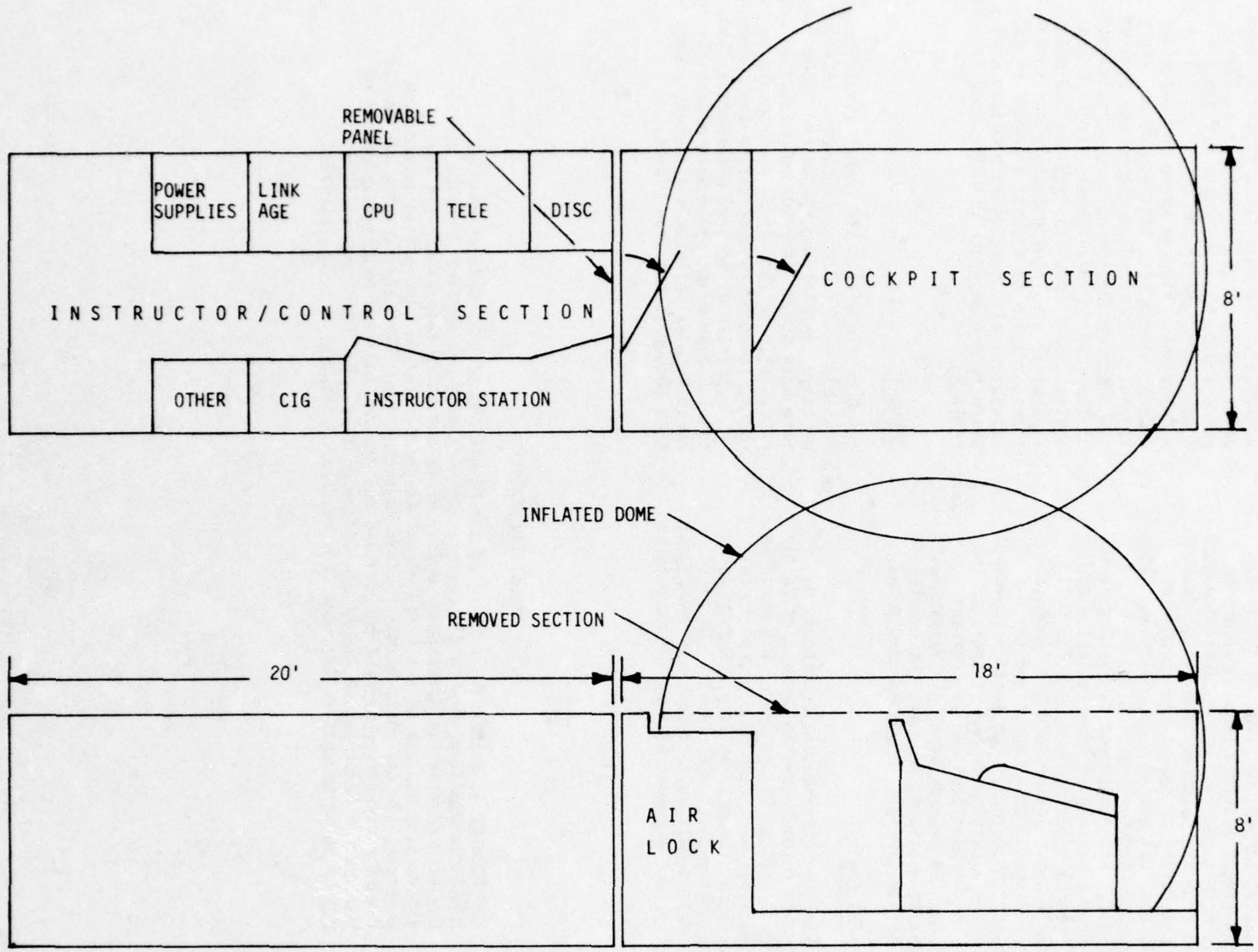

Figure 1. Proposed Layout - Air Transportable Programmable Air-to-Air Combat Simulator

the training to be provided, but it is the threat tactics, not aircraft performance, which are most subject to modification. The interactive target, or "Iron Pilot" should exhibit threat tactical considerations or should permit the instructor to provide such inputs from the console. The limitations of this simulation to one-on-one engagements limits tactical training to one-on-one situations but effective training can still be performed. Data on threat tactics is available from a variety of sources including intelligence organizations, the Tactical Fighter Weapons Center, AFM 3-1 "Tactical Fighter Weapons Employment," and the F-5 "Agressor" Squadrons. The tactics employed in a given situation depend strongly on the number of "friendlies" and adversaries involved. To provide tactical training with or against multiple aircraft, the simulation of multiple aircraft should be considered.

LOGISTICS CONCEPT

Field maintenance would probably be limited to removal and replacement of cards/modules. A 30 to 90 day spares kit would be carried along with each mobile trainer to ensure simulator availability. Repair would be accomplished at depot level. The simulator design will have to consider vibration, humidity, and extremes of heat and cold to be encountered during continuing moves. Design tradeoffs will be made between built-in test equipment (BITE) or separate supporting test equipment. The need for a self-contained power source or use of locally available power source will be traded off against the total weight and volume transportability considerations. Storage space for technical orders, spares kit, test equipment, and power source, if required, would become part of the simulator enclosure/shelter. Consideration of the need for maintenance, supply, and instructional areas may require the use of expandable simulator enclosure/shelters. Air transportation to support movement of the simulators will have to be provided with a priority commensurate with the need for the training.

SUMMARY

A mobile air-to-air combat simulator is feasible with today's technology. Advancements in computer and simulation technology make such a simulator not only feasible but practical. Further study work should be conducted in order to best define the approach. The expertise of several governmental/industrial groups seems applicable especially in areas such as inflatable structures, Bare Base concepts, and iron pilots.

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SIGNIFICANT FEATURES OF THE UNDERGRADUATE PILOT TRAINING - INSTRUMENT FLIGHT SIMULATOR (UPT-IFS) VISUAL/FLIGHT SYSTEM

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INTRODUCTION

The USAF Undergraduate Pilot Training-Instrument Flight Simulator (UPT-IFS) System design combines several state-of-the-art improvements that promise to provide a highly realistic and effective training alternative to actual flight training. A significant part of the UPT-IFS system is its Visual Subsystem and its relationship to the total simulator complex. Limitations of previous visual systems dictated the need for establishing minimum image quality requirements and associated test procedures for the UPT-IFS system. These included the utilization of image detail criteria in terms of image contrast as a function of resolution levels of modulation transfer function (MIF), the employment of raster transformation to achieve the required low eye-height, the use of a high resolution color Cathode-Ray Tube (CRT) in an infinity image display, optimized terrain modeling, and depth-of-field criteria.

BASIC UPT-IFS PLAN

The basic plan for the UPT-IFS, as formulated from a study back in 1968, was to acquire a training system using technology of proven training capability and reliability. Accordingly, companion programs were established for the flight simulator system with Singer Simulation Products Division and the Visual System with American Airlines/Redifon.

The combined systems were to provide high-fidelity training for all phases of instrument flight, including visual simulation of takeoff, approach, and landing (or missed approach).

THE VISUAL SYSTEM

The visual system offers an enhanced training capability by providing extra-instrument training cues for approaches and transitions to landings under variable weather conditions. It consists of two color television (TV) probe/model image generators feeding four cockpit display crew stations with infinity image visual cues of the outside world.

These cues are critical in that they allow practice of the two-way transition from instrument indications to eye-contact with terrain patterns and textures, runway surface markings, lighting configurations, and signals. Because of this criticality, comprehensive steps were taken to quantify and qualify the parameters that provide these cues. To provide these critical cues, the TV probe/model system was selected as best suited for the requirement in terms of desired performance, necessary flexibility, proven training value and reliability. Basic performance advantages of this approach were: unprogrammed maneuverability, a relatively high level of detailed imagery of day as well as night scenes, and sufficient promise of providing the necessary visual cues in near-the-ground conditions.

In order to optimize the probe/model approach, past shortcomings were addressed and special steps were taken to effect improvements.

IMAGE QUALITY CRITERIA

One of the principal tasks was the adaptation of established criteria for assuring and objectively measuring the quality of the displayed image in terms of resolution and contrast transfer (or modulation transfer) characteristics. As applied to TV systems, resolution may be defined as the amount of distinguishable details in the display, normally expressed as the number of TV lines, observable in dimension, equal to the picture height. Traditional techniques of resolution verification have been mainly eyeball, or subjective determinations. In a study conducted by the Aerospace Medical Research Laboratories (AMRL) at Wright-Patterson Air Force Base, more objective-type measurement

techniques were developed. These established a direct relationship between video signal risetime (relating to image-to-object contrast) and TV resolution capability.

If a TV system is required to reproduce a gross black-to-white transition, consisting of resolution bar patterns, the video signal waveform would take virtually no time to moveup from a minimum black reference level to the maximum white response level. A complete square-wave replica of the bar pattern results. As the bar pattern intervals are reduced (to higher resolution spatial frequencies), and given the TV system's timing constraints, the move-up time reaches its practical limit, at or before the given interval is traversed. This results in just reaching (peaking) the maximum white level (100% contrast/modulation) or partially reaching that level (percentage modulation). Partial or percentage modulation, then, is suitable as a valuable tool in measuring resolution.

In adapting this concept and technique, a typical probe/model candidate system was used in a series of measurements for performance comparisons against known standards. Measurements of the system camera's gray scale, geometric distortion, and contrast transfer characteristics were performed through analysis of the video output signals, correlating to standard and special optical test patterns, viewed by the camera. The special patterns consisted of resolution charts, representative of four levels in spatial frequencies of 5, 7, 10, and 15 arc-minutes. With the camera set up to view a wide black-to-white transition pattern, a reference amplitude reading representing the lowest resolution was obtained, using a linefinding oscilloscope or waveform monitor. For each resolution level, the peak-to-peak amplitudes of the video signal waveform were noted. These amplitude swings, taken as percentages of the reference amplitude swing, served to reflect the modulation characteristics of the system. Measurements were taken for each of the three color channels, at nine different points within the field of view, and at simulated ranges of a half-mile and seven miles.

After analyzing and normalizing, the resulting measured parameters, as shown in Table 1., were made the required inputs into a stipulated final display device (CRT Monitor) of known characteristics and performance. Thus, system picture quality was controlled through specification (and measurement) of both camera image quality and display monitor performance.

DEPTH-OF-FIELD (DOF) REQUIREMENTS

In addition to the emphasis on the resolution/MTF parameters, particular attention was directed to assuring adequate DOF characteristics, another critical cue requirement. The conventional optical pickup was favored as a minimum risk item, even though it tended to have DOF limitations. To ascertain its performance, arrangements were made for visual systems with conventional pickups to be demonstrated and evaluated prior to contract award. The results were considered favorable. Further, an objective, "Twice-the-Risetime" method, (adapted from the earlier mentioned AMRL study) was employed to determine and measure DOF as a function of video signal risetime. With this method, an appropriate chart is used to obtain an optimum probe focus setting, corresponding to sharpness in image resolution. The video signal risetime is taken at this setting. The chart is then repositioned at points nearer to and away from the probe. The repositioned points are those at which the focus is degraded to the extent that the signal risetime is not more than twice that at the optimum focus setting. These points mark the near and far field limits. A plot showing the relationship is depicted in Figures 1 and 2.

USE OF RASTER TRANSFORMATION

The optical probe is the controlling component in a TV probe/model visual system. As such, the probe's closest approach to the model determines the minimum model scale, commensurate with the minimum required pilot eye-height. State-of-the-art probe technology, at the time, enabled a minimum probe-to-model approach to be achieved, that was sufficient for the 7.66 feet needed for the T-38 application. But for the T-37, a lower 5-feet eye-height was required. The technique of TV raster transformation, or anamorphic compression, was employed for reducing the physical eye-height to an apparent 5 feet. The transformation of the TV raster is achieved by means of electronic circuitry, driven by computer generated height signals, to change the scanning pattern of the camera. The picture height, width, and vertical linearity are changed as needed to provide the necessary aspect ratio, without allowing unsatisfactory side effects, such as corner cutting, registration shift, or brightness changes. A critical aspect of the transformation technique is to assure that the relationship of apparent distance above the terrain to that of the actual distance, is always greater than a ratio of 0.6 to avoid unrealistic or unsatisfactory image degradation when the video scanning is modified.

TABLE 1.

RESOLUTION REQUIREMENTS FOR VIDEO INPUT TO MONITOR

	PERCENTAGE MODULATION							
	7 Miles				0.5 Mile			
Position-within Field of View	5'	7'	10'	15'	5'	7'	10'	15'
C	15	35	90	95	15	30	90	95
CU		50	70	80		40	60	70
CD	10	50	80	85	10	40	70	80
LU, RU		15	40	50		15	40	60
LC, RC	10	25	60	75	10	25	60	75
LD, RD	10	20	45	55	10	15	40	60

NOTE:

For a $36^{\circ} \times 48^{\circ}$ FOV on the display .

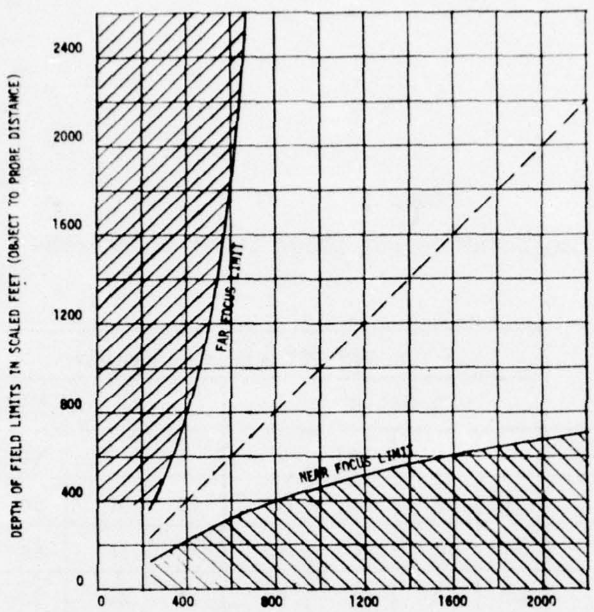
5' corresponds to 432 TV lines per picture height resolution.

7' corresponds to 309 TV lines per picture height resolution.

10' corresponds to 216 TV lines per picture height resolution.

15' corresponds to 144 TV lines per picture height resolution.

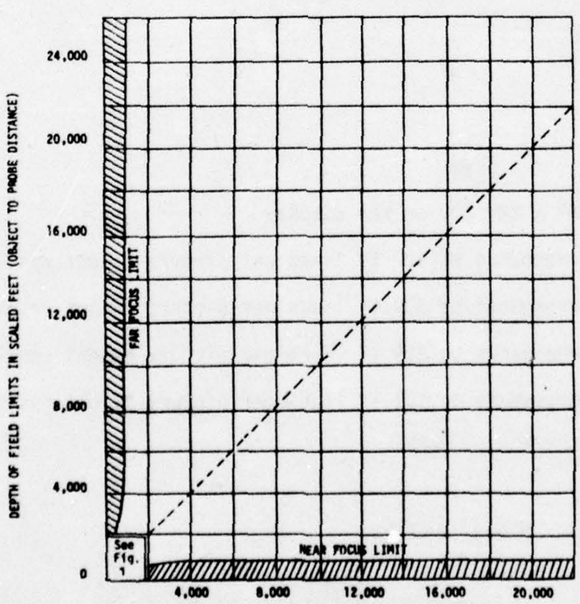
DEPTH OF FIELD VS OBJECT DISTANCE IN SHARP FOCUS



Probe to Object distance in sharp focus (scaled feet)
Focus servo limits for Probe and Camera
For 2:1 change in video rise time

Figure 1

DEPTH OF FIELD VS OBJECT DISTANCE IN SHARP FOCUS



Probe to Object distance in sharp focus (scaled feet)
Focus Servo Position
Limits for Probe and Camera for 2:1 change in video rise time

Figure 2

The rate of transformation into the height-above-the-model-terrain function must be introduced gradually and soon enough to avoid any noticeable transitioning.

HIGH RESOLUTION DISPLAY CATHODE-RAY TUBE

The next significant feature of the UPT-IFS visual system was the use of a high resolution, shadow mask type cathode-ray tube, which had been developed on an earlier program. The RCA developmental tube, originally designated Type C74957, is now a limited commercial production item listed as RCA 1908P22. The center resolution capability is given as approximately 900 lines with a white test pattern, having a brightness of 77-foot lamberts. Because of the prior favorable experience with this developmental component and an associated monitor chassis, this display tube was specified for use in the system. The advantages of using a CRT/monitor as image input into a mirror/beamsplitter design, are relatively low cost, high brightness, higher optical efficiency and less maintenance concerns, when compared with a projector type display package.

ON-AXIS INFINITY IMAGE SYSTEM

Yet another basic feature of the design, but representing significant advantages in realism, is the 60^{o} diagonal field of view, on-axis infinity or virtual image display package. The infinity image is produced by placing the image input at the focal plane of the spherical mirror. The advantage, inherent with a virtual image display, is its ability to present a scene in a collimated fashion, such that the eye perceives the image as focused at infinite distances, as in the real world.

An earlier concern involved the operational maintenance aspects of using acrylic versus glass as the material for the collimating mirror. After considering long-range advantages associated with glass against the more obvious factors of less cost and weight for acrylic, the former was selected for use. The beamsplitter is also glass.

Indications point to a compatible matching of the curve surfaces of the high resolution CRT and the spherical mirror design.

MODELING ENHANCEMENTS

Finally, in keeping with the basic plan, existing terrain modeling design was optimized to best suit the UPT-IFS application. Major efforts centered around minimizing facility size and power requirements. Accordingly, a common model scaling (2000:1) was able to accommodate the two different gaming area (5 X 10 and 6 X 12 nautical miles) requirements. Two different, typical terrain-scapes and airfield runway configurations were fashioned to provide training flexibility and to avoid the cost and complexity of customized modeling. The modeling scheme followed was to place emphasis on realism through the entire optical and video chain as presented to the pilot, rather than on a realistic looking model board. Previous experience had shown that model detials, coloration, and contrasts, for example, when modeled as in the real world, appear to be unsatisfactory in the display to the pilot.

SPECIAL EFFECTS

The integral design of the visual system is enhanced by a special effects "fog box," which electronically generates variable visibility restrictions, cloud tops, and ceilings. This fog box generator also provides each of the four simulator cockpits with a capability to fly into or above the clouds, even when the probe/model images are not available. The above-the-clouds effects generate a blue sky above adjustable shades of white to dark gray cloud tops. The sky/cloud tops "horizon" reference in the visual scene is designed to be fully and accurately responsive to aircraft pitch, roll, and altitude changes.

VISUAL SYSTEM PERFORMANCE

The UPT-IFS visual system has recently undergone engineering verification testing. These tests were extensive and included tests on the probe/camera combination, the distribution amplifiers and the display system. The MTF of the probe/camera complied with the requirements for all but a few points. In many instances, MTF significantly exceeded the minimum required. The only performance area causing concern involves limitations in the on-runway DOF characteristics. The DOF pattern appears as a band of reasonably sharp imagery sandwiched between "softer" image details in the foreground and background. Further qualification tests are being conducted on the system, as integrated with its host flight simulator, to assess overall performance adequacy.

INTEGRATED UPT-IFS SYSTEM

With the integration of the visual system with the "flight" portion of the UPT-IFS complex, critical assessments will be made as to the total systems effectiveness as originally envisioned. The host flight simulator brings as its share, several equally unique, state-of-the-art features.

This system employs a six-degree-of-freedom motion system for each cockpit, on-board instructor stations, advanced digital computation systems, automatic demonstration and aural briefing facilities, a playback capability, and the ability to synthesize emergency conditions. These capabilities, combined with the out-the-window cues of the visual system, are expected to make a major contribution in providing high fidelity synthetic training in a cost-effective manner for the Undergraduate Pilot Training Program.

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VERISIMILITUDE TESTING: A NEW APPROACH TO THE FLIGHT TESTING OF AIR FORCE SIMULATORS

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INTRODUCTION

The purpose of this paper is to explain the mechanics and rationale of an improved approach to simulator flight testing that the Air Force has been taking with its most recent simulator procurement. The goal has been to fly and test the simulator so as to identify problems that it may have had in performance and handling qualities. Problem identification has been done in a scientific manner and "tweaking" has been avoided. The test method that has been developed and used, I call verisimilitude testing.

"What is verisimilitude and what is verisimilitude testing?" you ask. Webster's dictionary[1] defines verisimilitude as "the appearance of being true or real." It is just that - how closely the simulator appears to be true or real - that is of interest in the end result. Verisimilitude testing is an approach to testing the performance and handling qualities of a simulator that permits determining just how closely the simulator appears to be true or real.

Recognizing that heretofore simulator testing, within the Air Force at least, has been a highly subjective, iterative process commonly referred to as "tweaking," verisimilitude testing is a somewhat different approach. It is an approach that seeks to determine how closely the simulator duplicates aircraft performance and handling qualities by applying aircraft flight test techniques to the simulator.

One assumption is critical to this approach. That assumption is that the results that are obtained by using standard flight test techniques can be related directly to the pilot's perception of how closely a simulator duplicates aircraft performance. Although there are undoubtedly some shortcomings in this assumption, the assumption should be basically sound.

REQUIREMENTS

The introduction of an ordered approach to simulator testing was considered to be necessary because of the slow, iterative, and frequently nonrepeatable results of "tweaking." The Acceptance Test Procedures written under contract (frequently by the simulator contractor) were clearly not the answer. This is because the Acceptance Test Procedures are written to tell the contractor whether or not he has programmed the math model that he thinks he has. Verisimilitude testing, on the other hand, is aimed at determining whether or not the contractor has programmed a math model that reflects the aircraft being simulated. The big advantages of verisimilitude testing over "tweaking" are that it can be used to compare known aircraft values to those of the simulator, it can be accomplished quickly, and it produces repeatable results.

The program on which this approach to simulator testing has been introduced is the Undergraduate Pilot Training-Instrument Flight Simulator (UPT-IFS) program. In this program two different aircraft are being simulated, the T-37 and T-38, both of which are used to train Air Force pilots. The simulators that are being procured have six-degree-of-freedom motion systems and incorporate a terrain model board visual system. The demands of the Air Force are that these simulators possess a high degree of fidelity (or verisimilitude!) with performance characteristics not "perceptibly different from the characteristics of the real world aircraft."[2] Since the level at which differences become perceptible is not specified and is furthermore not even known, the application of verisimilitude testing seeks to make objective comparisons between the simulator's and the aircraft's performance and handling qualities. Areas where any differences exist between the aircraft and the simulator can be more directly pinpointed and significant problem areas can be made the subject of necessary corrections.

Insuring that there are "no perceptible differences" between the performance of the simulator and that of the aircraft is not an easy task. When a simulator is subjected to "tweaking," the results reflect what a small group of pilots perceive to be differences between the performance characteristics of the simulator and that of the aircraft. There are a number of problems with this approach. Three of these problems bear closer scrutiny:

a. First, differences that are perceived may not exist as perceived. For example, a pilot might feel that control forces

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[1] Webster's New World Dictionary. Cleveland and New York: The World Publishing Company, 1958.

[2] Aeronautical Systems Division. ASD Exhibit ENCT 73-1, Wright-Patterson AFB, Ohio, 5 Nov 73.

are too high to produce a given roll rate. What bothers the pilot is his perception of control force, but the problem may not be one of incorrect control forces at all. It could be that stick deflection is too little for a given force or that aerodynamic aileron control power is too little. In other words, the pilot can identify what surfaces in his sensory perception as a problem, but will likely be unable to identify the source of such problems.

b. Second, a pilot might identify a problem that is really not a problem at all, or he may exaggerate the extent of a perceived problem. What is happening is that the pilot's memory is not total, and it is playing tricks on him. This is not as far fetched as one might imagine. Doing away with "tweaking" by making direct objective comparisons, however, easily overcomes this shortcoming of the "tweaking" approach to testing.

c. Third, "tweaking" does not produce highly repeatable results. The lack of repeatability is due in part to individual differences among pilots and in part to the complex interrelationships of the various facets of simulation.

A DIFFERENT APPROACH

In order to avoid the problems inherent in "tweaking," the verisimilitude approach to testing has been developed. This approach has both a quantitative side and a subjective side. Since the Air Force was virtually guaranteed satisfaction on the UPT-IFS program through the contractual requirement specifying no perceptible differences in performance characteristics, neither a quantitative nor a subjective evaluation could be ignored.

The objective portion of verisimilitude testing begins with a test plan written to allow extracting data from the simulator that can be compared to available aircraft data. This test plan must be written to take advantage of flight test results from the simulated aircraft. For the UPT-IFS T-37 simulator, a short series of flight tests was necessary to fill in some required data that was not available.

Test techniques were not specified in the test plan. The test techniques used, however, were consistent with those used in USAF aircraft flight testing.[3] The test pilots detailed to this project were thoroughly familiar with the use of these test techniques and had flown test profiles in an instrumented T-37 aircraft to collect flight test data.

Quantitative data collection in the simulator was somewhat of a problem. It was found that the computer output line printer was best used for some tests while a strip recorder was required for others. The line printer was extremely useful for testing level accelerations and decelerations, climbs and descents, and longitudinal and lateral directional static stability. The strip recorder had to be used for all dynamic tests, maneuvering flights, stalls, and spins. Since the strip recorder was run in real-time, it could be set up to record the desired parameters with optimum scaling and speed. This capability greatly facilitated reading data from the strip chart.

Once collected, the data were reduced and plotted for comparison with aircraft flight test results. Reduction of simulator data was greatly simplified by programming the simulator to duplicate aircraft test conditions. Reduction to standard day conditions was eliminated by setting the simulated environment to standard day conditions. For comparison purposes, flight test results were scaled and plotted on graph paper so as to allow the direct comparison between simulator and aircraft flight test results. The comparative plots were the heart of the quantitative test results since these plots were used to pinpoint and describe simulator inaccuracies.

The greatest difficulty in using this approach was interpreting the results. One must remember that the products of standard aircraft flight test techniques are only reflections of the equations that describe an aircraft's flight. The effects of various components of these equations are frequently interrelated, making it difficult to relate the results of standard flight tests to the equations of motion that are used to program a simulator. This difficulty can be largely overcome by using an experienced test pilot and flight test engineer to collect and interpret the aircraft and simulator flight test data. Using conventional flight test techniques, applied by an experienced test pilot and flight test engineer, therefore, allows us to move from "tweaking" to the more orderly and scientific approach of simulator verisimilitude testing.

Even with the introduction of quantitative tests for comparison purposes, the use of subjective testing has not been ignored. Subjective testing was planned early in the UPT-IFS program by the Air Training Command.

[3]USAF Test Pilot School. Stability & Control, AFFTC-TIH-74-2, Edwards AFB, CA, July 1974. USAF Test Pilot School, Performance, and FTC-TIH-70-1001, Edwards AFB, CA, January 1973.

Valuable assistance in this area has been provided by an Air Force Institute of Technology student who accepted this project for his Master's thesis. In order to produce meaningful results, it was necessary to achieve response repeatability, to eliminate random responses, and to insure that the test subjects represented a fair cross section of Air Training Command instructor pilots.

In preparation for the subjective testing, a questionnaire was prepared by the Air Training Command to insure that each pilot responded to the same questions. Two separate test missions were planned for each pilot participating in the subjective evaluation. Each of these missions was broken down into specific maneuvers, and questions regarding the perception of fidelity were written for each maneuver. The maneuvers planned included all maneuvers that might be trained in the simulator. Questionnaire responses were structured so that each pilot would be required to make one or more dichotomous decisions in order to rank the simulator's performance.

When the questionnaires have been completed and the results are compiled, analysis of the results will be accomplished by use of a computer program. The computer program will aid in the analysis of the results by illuminating areas where correlations can be made. The correlations, where noted, will be used to determine where significant problem areas may exist. Although few, if any, unknown problem areas should exist following the quantitative tesing, the results of the subjective testing should corroborate the quantitative findings.

The subjective tests should be of greatest utility in determining where problems exist with the integration of visual and motion cues in the total simulation. The subjective tests may also provide a valuable input to the Air Training Command in structuring their simulator training program.

Foremost to note in the structuring of this approach to simulator testing is that "tweaking" has been carefully avoided. This is because "tweaking" is an iterative process and is not only time consuming, but may also result in making changes that could affect the results of tests that have already been completed. This does not mean that some obvious problems cannot be corrected on the spot, but problems that are corrected on the spot must not affect data that have already been collected. For that reason, it is fairly critical that the full series of quantitative tests be completed prior to the correction of any deficiencies. Because of the nature of the subjective tests, it is even more critical that the full series of subjective tests be completed prior to the correction of any deficiencies.

LIMITATIONS

Although this balanced approach to simulator testing is a great improvement over "tweaking" the simulator to achieve verisimilitude or fidelity, there are also some disadvantages. First, there are no tolerances to use as quidelines. Although some tolerances should probably be developed, applying tolerances indiscriminately would be almost meaningless. Therefore, the opinion of a trained test pilot must be used in lieu of arbitrary tolerances when evaluating the performance and handling qualities of a simulator.

Second, this approach to testing a simulator cannot accurately probe the pilot's perception of the programmed math model. What is meant is that the perceived stability and control derivatives may be different than those that are programmed. Because of the time delays that exist from pilot input to total system response and because of such factors as motion system washout, visual system scaling, and control loading system inaccuracies, it is likely that there is a considerable difference between the model that the pilot perceives in a simulator and what he would perceive in the aircraft with virtually the same equations of motion. For this reason, an accurate math model may not always produce an accurate simulation. A meaningful test that would yield the components of the perceived math model is not available. Therefore, an impasse could be reached if the subjective feel is that the fidelity of the simulator is not satisfactory but the quantitative tests yield no significant problems.

The above two limitations appear to be the most significant, but by no means the only limitations of verisimilitude testing. For example, tests requiring outside references for optimum performance are constrained by the limitations of the visual system. These limitations on verisimilitude testing, however, should not be overemphasized.

TEST PROGRESS

The first round of quantitative tests have already been completed on the UPT-IFS T-37 simulator and the data have been analyzed. The analyses detected evidence of common problems turning up in more than one test. This recurrence of certain common problems helped to pinpoint specific problems. Once the deficiencies have been noted and corrected, round two of the quantitative testing can take place. Following the correction of the

deficiencies noted in round two of the quantitative testing, the subjective tests can begin. Should any deficiencies remain at the commencement of the subjective testing, the results of the subjective tests should either confirm or deny the severity of any such problems. This should provide a form of check and balance concerning the necessity of certain corrective actions.

Where will verisimilitude testing go after it has been conducted on the T-37 and T-38 simulators being procured under the UPT-IFS program? Thus far this approach to simulator flight testing has shown great promise. Given its continued success as an efficient means to test the fidelity of simulator performance and handling qualities, it will likely be used on other simulator procurements now in progress. Verisimilitude testing is a very flexible approach to simulator flight testing and can be easily tailored to meet the demands of the situation.

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EVALUATION OF THE SYNTHETIC FLIGHT TRAINING SYSTEM (DEVICE 2B24) FOR MAINTAINING IFR PROFICIENCY AMONG EXPERIENCED PILOTS

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BACKGROUND

Since the early days of flying, flight simulators have been in use and their value has been amply demonstrated. Flight simulators have evolved from the Link Trainer, which was widely used for pilot training in the Second World War, into precisely engineered devices capable of accurately computing the aerodynamic responses of an airplane to control inputs, and of reproducing realistic cockpit instrument indications for all flight situations. It was realized, as Adams (1957) points out, that flight simulators have many advantages over the operational situation. First, the simulator provides its users with greater control over ambient conditions. Whereas the "real" world is subject to unpredictable variations, a simulator can provide planned variation of various elements of the real situation with unessential elements in the real situation omitted. Second, the simulator can represent dangerous elements in flight more safely. Emergency procedures that would be too dangerous to teach in the air may be taught safely in ground-based simulators. Third, a major advantage offered by simulators is their low operating costs in comparison with the costs of operating aircraft. For these reasons, simulators continue to play an important role in pilot training during initial acquisition, transition training, and for maintenance of established flying skills. The importance attached to simulators in meeting training goals is, of course, predicated on the assumption that training given in the simulator will transfer to the aircraft.

Although there has never been a serious challenge concerning the value of simulators to pilot training, the utility of simulator training for maintaining the proficiency of experienced pilots has not been adequately established. The various studies that have assessed the training effectiveness of a specific flight simulator for maintaining pilot proficiency among experienced pilots have sometimes produced contradictory results (Caro, 1971; Crook, 1965; American Airlines, Inc., 1969; TransWorld Airlines, 1969). For example, whereas Caro reports positive transfer from the simulator to the aircraft among experienced pilots, Crook reports less conclusive findings. Three somewhat different explanations for these discrepant findings have been suggested. First, the variance in flying skill among experienced pilots is often greater than among student pilots who bring little, if any, initial skill to the task (McGrath and Harris, 1971). In performance training it is well known that the beneficial effects of training varies as a function of experience or skill level (Briggs, 1957; Roscoe, 1971); that is, the same training simulator may exhibit different effectiveness functions for different levels of pilot experience or skill. To the extent that experienced pilots are not carefully matched in terms of flying skill, the significance of assessing what can be learned in the simulator is diminished. Second, most performance measures used were judgmental in nature and, thus, highly subjective evaluation instruments. Third, instructional techniques may vary widely depending upon the ability and attitudes of the instructor pilots. In considering the possibilities of such instructional differences, it is essential to determine the utility of simulator training independent of the instructor variable.

Currently, there is a need to determine the training value of Device 2B24, a high-fidelity simulator, for maintaining instrument flight (IFR) proficiency among experienced Army helicopter pilots in the 'H-1H aircraft. This paper reports on the transfer effectiveness of Device 2B24 for use in maintaining IFR skills among experienced pilots as compared to inflight training. As will be seen below, this study extends previous studies by more adequate control of pilot and instructor variability and through more objective measures of pilot performance obtained both before and after training in Device 2B24.

METHOD

Pilots. The pilots participating in this study were 36 fully qualified, combat ready Army aviators. The sample was comprised of both warrant and commissioned

officers, all of whom had between 400-600 hours of rotary wing flight experience. Two groups of aviators of 18 pilots each were formed on the basis of a composite score on three IFR performance measures. A written test on instrument procedures (I), a standardized IFR check ride in the UH-1H helicopter (H), and a standardized IFR check ride in Device 2B24 (S) were the three measures making up the composite score (P). The a priori scoring formula reads: $P = .5\,I + S + H$. The three performance measures were administered to each of 51 experienced pilots assigned to the 101st Aviation Group, Ft. Campbell, Kentucky. The best 18 and the poorest 18 scores were used for group matching and for control of differences in initial ability. The two groups are referred to as "high" and "low," respectively.

Following the selection of each group, pilots from each group were quasi-randomly assigned to one of three IFR training modes under the following conditions:

a. Simulator training with Device 2B24.

b. Inflight training in the UH-1H.

c. A combination of simulator and inflight training divided equally.

A total of 12 pilots, 6 from each group, were assigned to each training mode. This procedure provided an opportunity not only to evaluate training modes but to evaluate them with respect to initial skill level among pilots. An analysis of variance failed to show reliable differences between pilots assigned to each training mode ($F(2,30) = .31$), but revealed a reliable difference between the pilot groups assigned within each mode ($F(1,30) = 17.91$, $p < .001$) as constituted. Thus, pilots appeared to be effectively matched among training modes while differentiated in terms of initial IFR skills.

Procedure. The pilots in each of the three training modes were given a total of 12 hours of IFR training during 9 months of testing in each of the three training modes--that is, in the SFTS, inflight, or combined SFTS and inflight training.* The 12 hours of training were divided into 4 hourly increments taken quarterly. At the end of each quarterly (3 month) period, pilots were required to take a standardized IFR check ride in the UH-1H, identical in all its essentials with the IFR check ride given before training.

Prior to testing, an objective inventory for pilot evaluation was developed at the Ft. Campbell facility. The decisions to include items were based upon desired terminal flight behavior for experienced Army pilots. Evaluated tasks were arranged into a standard flight sequence, including both objective and subjective items. The inventory evaluated performance on each of five quantitative variables with one to four items for each variable scored on an appropriate scale. Equal weights were given to each of the objective variables measured; namely: (1) flight planning, (2) departure and enroute procedures (e.g., navigation and tracking, radio reports), (3) holding and arrival procedures (e.g., missed approach, time, track, airspeed, etc.), (4) ATC procedures, and (5) aircraft control (e.g., airspeed, altitude, heading, etc.). All scored items were completed during flight. A score of 100 represented "errorless" performance.

To minimize the effects of instructor differences, six instructor pilots (IP) were given familiarization training on the use of the flight inventory before each check ride. The order in which IP's were assigned to provide check rides was varied systematically. In addition, knowledge of an individual pilot's ranking and group assignment was withheld from the IP's to prevent such information from influencing their judgment. Nevertheless, because of the relatively small pilot sample, some IP's were aware of a particular pilot's group assignment.

Instrument flight training began soon after the two groups of pilots were formed. Training sessions were 1 hour in length and four sessions completed a quarterly training period. At the end of each quarter of training, an instrument check ride in the UH-1H was given to each pilot using the flight inventory for scoring pilot performance. The present paper reports on some initial findings of the transfer effectiveness of Device 2B24 among experienced pilots.

RESULTS

Because of conditions not related to the experimental variables, two of our pilots assigned to the "low" group, one in the SFTS training mode and the other

*The experiment was originally designed to provide 16 hours of training divided into four quarterly increments. We were unable to complete the last quarterly test period due to the temporary transfer of the pilots to a new duty station.

in the combined training mode were unable to complete the experiment during the third quarter testing period. The third quarter results and the statistical analyses are based then on an unequal number of pilots among blocks.

The main results deal with the differences in check-ride performance following training in the three training modes and the percent change in performance representing the differences between check-ride performance obtained before and after training. The curves in Figure 1 compare mean inflight performance for the three training modes over the three test periods with baseline performance plotted separately. The curves show that over test periods the changes due to training were not the same for each group, although the relative level of performance for the different training modes persisted throughout training. That

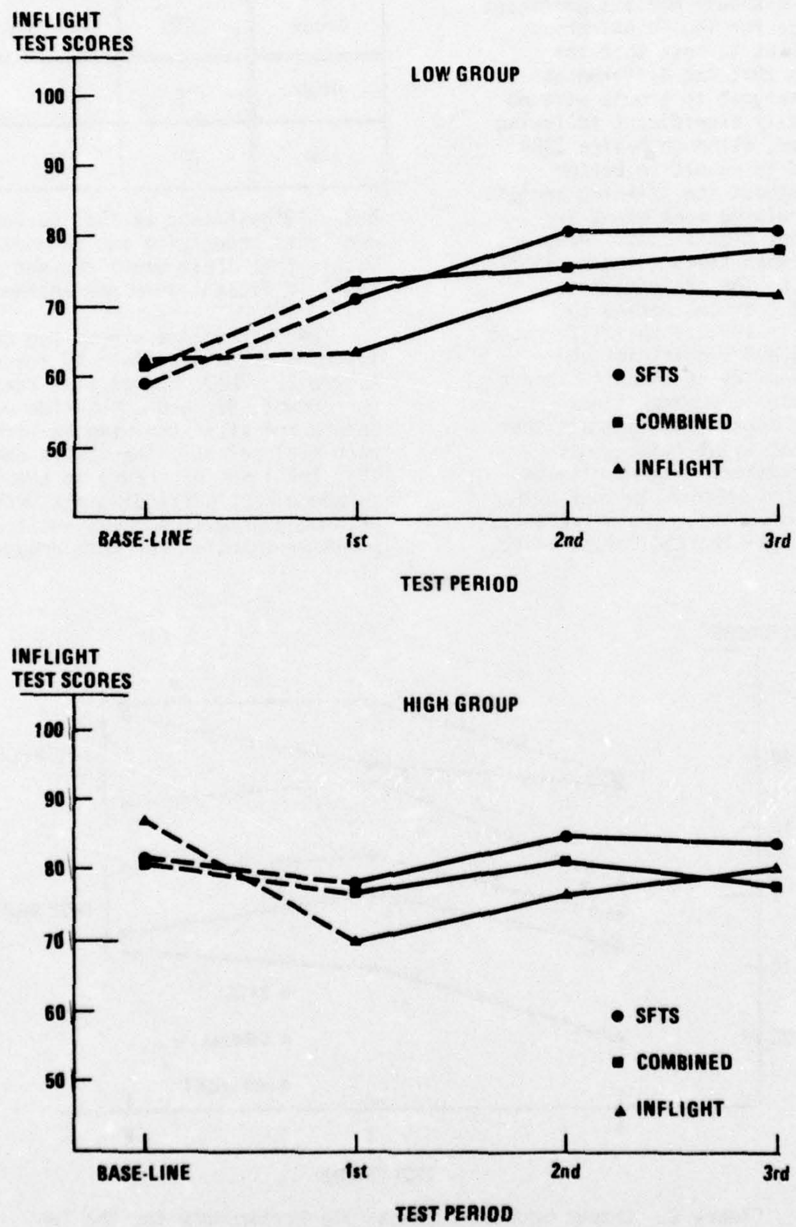

Figure 1. Learning Curves of Check-ride Performance for the Three Training Modes and Two Pilot Groups.

is, while the three curves for the "low" group showed marked learning effects over test periods, the"high" group gave very little evidence of learning. Both groups however, showed that check-ride performance was, in general, best for Device 2B24 training and poorest for inflight training. Analysis of variance for repeated measures indicate that variation in performance due to test periods was significant, $F(2,46) = 17.9$, $p < .01$, for the "low" group, although not a significant source of variance for the "high" group. It is also important to note that the analysis revealed that the differences between pilots assigned to groups were no longer statistically significant following training. Further, although Device 2B24 training appeared to result in better performance throughout the training period, F tests of the training mode means for each group were not significant. However, Duncan multiple range tests (Duncan, 1955) were carried out on the training mode means of the last training period to determine which, if any, of the differences between the means are significant and which are not. Results of these tests are summarized in Table 1. Common lines underlying two or more means indicate that these means are not significantly different from one another. The results on means for the third training period indicate that for the low group the mean differences between inflight training and Device 2B24 training were significantly different. All other comparisons were not significant. Thus, the value of Device 2B24 is particularly apparent for the low group.

Table 1

RESULTS OF RANGE TEST OF THE DIFFERENCES BETWEEN PERFORMANCE SCORE MEANS FOR TRAINING MODE AND PILOT GROUP

Group	SFTS	Combined	Inflight
High	84	78	81
Low	81	79	72

Note: Significant at the .05 level. Common lines underlying two or more means indicate that these means are not significantly different from one another.

Percent change scores for the three training modes are given by the curves of Figure 2. These curves plot the difference, in percent, between check-ride performance before and after training in each mode and each test period. The curves show again that the level of change in check-ride performance were quite distinct, with the SFTS mode producing the highest degree of positive transfer for both groups. The

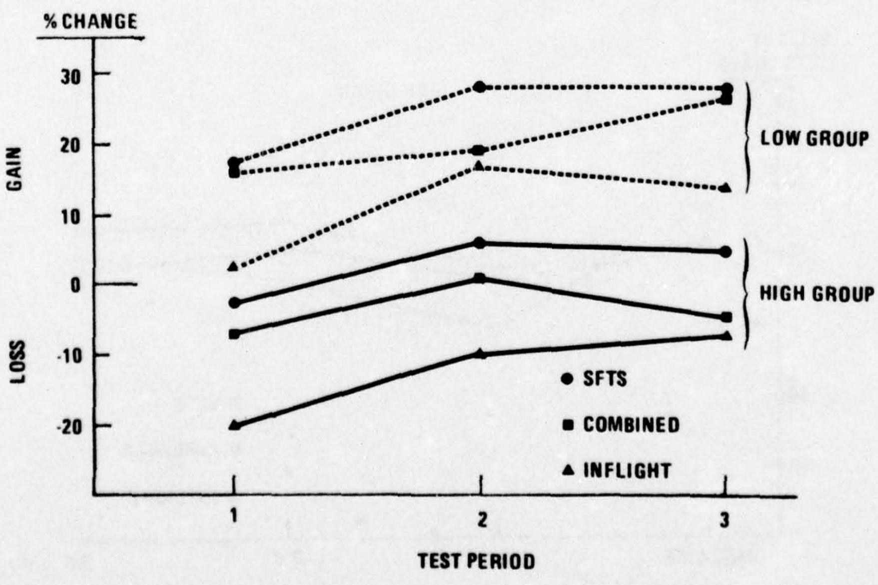

Figure 2. Change Scores in Check-ride Performance for the Two Pilot Groups as a Function of Training Mode and Test Periods.

plot of these test period scores show that most of the performance changes that occurred took place by the second test period. It may be noted, for example, that all of the transfer that occurred for Device 2B24 training occurred by the second test period; that is, after 8 hours of training in Device 2B24. Thus, the loss of the fourth test period did not appear to be crucial to the present interpretation of our results.

A three-way analysis of variance, encompassing groups, training modes and test periods, was carried out on the change score data. Results of the analysis related to the principal variables, and their first order interactions indicate that only the variations due to groups and test periods were statistically significant at the .025 and .01 levels, respectively.

Duncan multiple-range tests were again carried out on the training mode change scores for the third measurement period. The results are shown in Table 2.

Table 2

RESULTS OF RANGE TESTS OF THE DIFFERENCES BETWEEN PERCENT CHANGE SCORE MEANS FOR TRAINING MODE AND PILOT GROUP

Group	SFTS	Combined	Inflight
High	5	-4	-7
Low	28	27	14

Note: Significant at the .05 level. Common lines underlying two or more means indicate that these means are not significantly different from one another.

Negative values in Table 2 indicate a percentage decrement in performance associated with training. This decrement, we believe, is in accord with normal variation in performance that may be expected with a pilot group already at a high level of IFR proficiency prior to training. The results on change scores indicate that Device 2B24 training and inflight training show the greatest number of significant differences consistent with the evidence of beneficial effects for SFTS training when compared to inflight training.

DISCUSSION

The objective of this research was to determine the extent to which IFR skills acquired during simulator training in Device 2B24, or inflight, or in combination, maintained or even enhanced subsequent performance in the UH-1H among experienced pilots. In this research the transfer effectiveness of the simulator is measured by determining the extent to which performance of Device 2B24 trained groups are equal to or exceed the performance of the inflight trained group on the criterion check ride.

The results of this study indicate substantial positive transfer of training from Device 2B24 to the UH-1H helicopter as evidenced by the fact that simulator training produced as good or better overall performance as inflight training. Thus, Device 2B24 training appeared to be as much a factor in maintaining IFR skills among experienced Army pilots as inflight training for the periods of time tested. These findings were characteristic of both groups of pilots. Further, the results showed that the beneficial effects of training were more often observed among pilots who demonstrated the least IFR skill level as measured by our criterion check ride. The consequences of our training procedures were that the initial differences in IFR performance between our two groups of pilots were no longer significant.

The fact that IFR training in Device 2B24 transfers to the UH-1H is not surprising since it is a high-fidelity simulator of the UH-1H helicopter. These results are also consistent with the record of commercial aviation which has shown that simulators can provide an effective means of providing training for highly experienced pilots.

It should be emphasized, however, that the effectiveness of any training device depends upon how it is used; it is influenced by all the well-known variables concerning conditions favorable and unfavorable to learning. Prophet (1966) has pointed out that a simulator is a training tool and, as such, is going to produce results no better than the quality of the training program of which it is a part. The evidence of transfer in the present study may well be attributed to the training program rather than simulator design alone. It is possible, for example, that if inflight training was conducted differently--that is, with a different training program--some evidence of additional benefits might be found.

The present findings complement past results which demonstrate the operational utility of simulator training (Caro, 1972; Woodruff and Smith, 1974). In particular, this preliminary analysis of the data indicate that much of the instrument training

now conducted in rotary wing aircraft can be conducted more efficiently on the ground. Although with Device 2B24 pilots may require approximately the same number of hours training as in the aircraft, the total time required is actually reduced by reason of the greater availability of the simulator and the elimination of much of the aircraft preparation time. The safety associated with elimination of much of the inflight training time, the release of aircraft for operational flights, and decreased cost of operating the simulator rather than an aircraft for training, all add up to a highly positive evaluation of Device 2B24 for the maintenance of IFR pilot proficiency. A reasonable conclusion from this study is that some evidence was found to support the assumption that simulator training administered in Device 2B24 can maintain, and perhaps improve, subsequent pilot performance in a tactical instrument situation. Whether or not the attitudes of the pilots who served as our subjects are in accord with this interpretation, is presently under review.

ACKNOWLEDGMENTS

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COMBAT READINESS THROUGH ENGAGEMENT SIMULATION

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For nearly three years the US Army has been experimenting with, refining, and implementing a series of training techniques which employ engagement simulation mechanisms, along with proven instructional models, to improve unit tactical training. Some see the advent of engagement simulation as merely another step along the Army's path toward increased realism in training. Others see engagement simulation as a near perfect simulation of combat, while still others believe engagement simulation is nothing new, and that in one form or another, "we have been doing this kind of thing for years." Probably none of the foregoing opinions on engagement simulation are entirely right, nor are any totally incorrect. More properly, the techniques at issue certainly simulate the violent interactions of weapons in combat, although imperfectly, and in so doing add much realism to our tactical training. While we can point to excellent training with conventional techniques, some of the aspects of engagement simulation are truly new, or are at least substantial revisions of earlier ways of doing things.

The main thrust of engagement simulation has been directed toward small unit tactical training. Tactical training is a complex undertaking which we have normally handled by attempting to break it down into its lowest common denominator or component tasks: firing a weapon, operating a radio, writing an order, or adjusting artillery fire. We train on these component tasks, and presume that in combat we can sum them into an effective whole. But until very recently we have had no means, short of combat, of actually testing our summations. Engagement simulation provides us one means of doing just that.

In an academic manner, engagement simulation can be defined as the employment of systems or devices to simulate with a high degree of fidelity the casualty producing effects of weapons found on the modern battlefield, during two-sided, free-play, tactical exercises. But what do we really mean by engagement simulation? In simple terms, we seek a believable way to say to the soldier in tactical training exercises, "You exposed yourself on this training battlefield in such a manner that an opposing soldier was able to draw a bead on you with his rifle, or put artillery fire on you, or with some other weapon, has caused you to become a casualty." For engagement simulation to be effective, the soldier must accept two things: first. he did indeed expose himself and get "hit," and second, this training occurrence has a one-for-one correspondence to combat. In his own mind the soldier must forge the link between a "casualty" in training and in combat. When we thus confront him in a credible manner, he responds as he seldom did to other training. Our initial field evaluations of engagement simulation clearly establish that without further prompting, the average soldier will recognize his error, and take action to preclude a recurrence of the mistake that led to his being "hit." While he will surely make other mistakes in other exercises, he rapidly learns through additional repetitions the fundamental lessons of combat, and modifies his behavior in a manner that influences and increases his chances of survival. When we have soldiers with the skills to survive in combat who use concealment, exploit all available cover, and employ suppressive fire to facilitate movement, we can turn our attention to training small tactical units in teamwork.

The objective of small unit tactical training is to provide combat units with the skills required to fight and survive on the modern battlefield. It differs from other types of training in that it must realistically simulate the combat environment. This environment involves the aforementioned violent interaction of two opposing forces who are out to destroy one another. To prepare our combat units to operate effectively in this environment, it is necessary to train them to operate against a realistic

opposing force. It is not sufficient to merely train our units to fire at the enemy; we must train them to fire and move against an enemy which is firing back, and doing everything in its power to neutralize or avoid our fire.

Perhaps the contribution that engagement simulation makes to tactical training is most easily understood by comparing it with traditional forms of combat training. Up until recently all of our tactical field exercises took one of two forms--live ammunition against cardboard targets, or blank ammunition fired toward a live opponent.

The effectiveness of live fire exercises against cardboard targets is somewhat deceptive. They often sound, smell, and look so much like combat that commanders are lulled into assuming they realistically simulate combat. Careful analysis, however, shows that they bear only a superficial resemblance to battle. Cardboard targets can not shoot back and hence scarcely represent the skilled and determined enemy we will face in combat; they don't try to hide themselves from us, and they don't try to suppress our fire. As a result, soldiers well trained with live fire exercises often encounter a tremendous shock when they first encounter real opposition, not because of the noise of combat, but because they are opposed by a determined enemy which they almost never see, which is trying to kill them, and which seems almost impervious to their fire.

Blank fire exercises enable us to deal more effectively with the enemy because they permit two opposing forces to maneuver against one another, signaling an engagement by shooting blanks. However, while the blank rounds realistically simulate the act of firing, they provide no indication whatsoever of the effectiveness of the fire. This determination is left entirely to the subjective judgement of the NCO or officer who is controlling the exercise. Since he will normally be required to deal with many soldiers, and a relatively large number of diverse weapons in a fast moving, complex situation, and since he can often see only a portion of the entire action at any one time, his judgements are frequently quite general in nature--"this side won because it was four times larger" or "that side won because it had better cover and concealment." While information of this type is of some value in training combat units, it falls far short of that required to develop truly skilled and battlewise soldiers.

Engagement simulation training systems overcome the shortcomings of both live and blank fire training methods. Engagement simulation consists of three steps, each of which encompasses a singularly important, and essential, training function.

Step 1 involves realistically exposing the soldier to the lethality of weapons. We equip each soldier's weapon, each armored vehicle, and each weapon crew with devices which realistically simulate its casualty producing capability. Once so equipped, two opposing forces conduct a free-play tactical exercise under no more, or no less, constraints than exist on an actual battlefield. The employment of the simulation devices enables the battle to unfold exactly as it would in combat. When a soldier fires and hits another soldier, the soldier who is hit receives an immediate indication he has made a mistake, and is "out of action." Likewise, if the soldier who is firing does not take adequate precautions, he can be hit by return fire. In this manner, each soldier taking part in the engagement simulation exercise receives immediate feedback concerning his actions. If he uses proper techniques and tactics in each situation he encounters, he continues to contribute to his team; if he does not, he is eliminated. Immediate feedback is an essential element of all effective training systems; but until the development of engagement simulation training systems, we had no reliable way of obtaining it during tactical training.

Step 2 involves confronting each soldier with a critique of his actions, and begins at the completion of the two-sided, free-play tactical exercise. We bring both forces together and conduct a detailed afteraction review. During this review, each soldier who has hit an opponent explains in detail how he was able to detect and engage him. This is followed by a mutual discussion of what the soldier who was hit could have done to prevent this happening. In this manner the techniques and tactics which enable soldiers to succeed are identified and discussed. Unlike traditional critiques which normally only involve the officer or NCO in charge lecturing the soldiers on mistakes he observed, these afteraction reviews get all the soldiers directly involved in the learning process. The officer or NCO in charge merely guides the discussion and summarizes key points. During field evaluations of engagement simulation training, it quickly becomes apparent that the most important training occurs during step 2, because it is during this step that the soldiers "learn" from their successes and mistakes.

Step 3 consists of successive repetitions of two-sided, free-play tactical exercises and afteraction reviews. During this step the soldiers have an opportunity to employ

and reinforce their new skills, try out new tactics or techniques, and in turn gain additional skills. Successive repetitions of tactical exercises are an essential element of engagement simulation training, exposing soldiers to the complex interactions of ground weapons and tactics. The techniques required to fight and survive on the battlefield cannot be mastered in only one or two exercises. Repetition teaches coping with lethality, and adds another important feature--competition. Since the soldiers trained quickly perceive that it is entirely within their power to team up to eliminate "enemy" soldiers and accomplish their team mission in the process, they begin to view the training exercises as a contest. Each time they take part in an engagement simulation exercise they become more determined to defeat the opposing force. When they lose, they pay particular attention during after-action reviews, and seek help from their leaders during breaks in order to develop the skills which will enable them to win the next time.

At the current time, two engagement simulation systems have been developed and their implementation throughout the Army is nearing completion.

The first system is called SCOPES, an acronym for Squad Combat Operations Exercise, Simulated. In this simulation, a six power telescope is attached to each soldier's rifle and three inch two-digit numbers are affixed to his helmet. The size of the number and the power of the telescope were chosen to simulate the weapon effect, in that the probability of reading another soldier's helmet number through the telescope at any given range, is close to the probability of hitting the soldier with live ammunition at the same range. When a soldier can read another soldier's number through his telescope, he fires a blank and calls out the number. The controller with his fire team then radios it to the controller with the opposing fire team. That controller informs the soldier wearing the called number that he is a casualty and requires the soldier to remove his helmet and remain in place until the termination of the exercise. SCOPES was implemented Army-wide by the US Army Infantry School in 1974.

In early 1974 the US Army Research Institute (ARI) expanded SCOPES to permit the employment of artillery support, mines, tanks, and antitank weapons during two-sided, platoon level exercises. This system, known as REALTRAIN, has just been implemented in US Army Europe. Implementation in the remainder of the Army will commence later this year.

The next generation of engagement simulation devices is currently undergoing development. It involves a higher fidelity simulation of weapons than telescopes and numbers, but being more complex, it will be some years before it is fielded. Known as the Multiple Integrated Laser Engagement System (MILES), this approach uses low-power-eye-safe lasers to simulate the firing and effects of the direct fire weapons found on the modern battlefield. MILES consists of a series or family of laser devices, which are being developed for the M16 rifle, the full family of machineguns, the VIPER, DRAGON and TOW antitank weapons, the main battle tanks (M60A1, A2, A3), and the M551 Sheridan. Follow on efforts will expand MILES into air defense weapons, helicopter air-ground engagement systems, USAF aircraft and munitions, and eventually enemy weapons systems. The prototype packages consist of laser transmitters which simulate the direct fire characteristics of the weapon involved, a laser detector array which detects and decodes incoming laser signals, and hit indicating mechanisms which combine audio and visual signals to convey near misses, hits which are not kills, and kills. Each device is to be lightweight, and of such size and shape that its addition to the base weapon will not affect the normal handling, accuracy, or performance of that weapon. MILES includes a provision for a hierarchy of weapons effects. An infantryman, for example, can "kill" another infantryman with his M16 laser device, but cannot disable a tank. Conversely, a tank can "kill" not only another tank but also TOW crews and infantrymen. The key to this discrimination is distinct pulse codes for each weapon, and discrimination logic in each detector.

We anticipate that when MILES is fully fielded, it will add a previously unknown element to the credibility, immediacy, and effectiveness of casualty assessment on the training battlefield. Given the development of the proper software to support the system (work which is already underway by the Army Research Institute) MILES has the potential to revolutionize military training.

The foregoing has described the state-of-the-art of engagement simulation and summarized the theoretical foundations of why and how it should work; that is, modify soldier behavior in the desired direction, and foster soldier learning. But we have still left unanswered the question, "Does it work in the real world?" Our evaluations over the past two years, principally involving SCOPES and REALTRAIN, tell us that it does.

The US Army Training and Doctrine Command (TRADOC) has just concluded a six-month joint

effort with US Army Europe and ARI to implement REALTRAIN in the divisions in Europe. While this effort was principally directed toward training controllers, a great deal of tactical training and data collection took place as well. While not all of the data has been analyzed or even examined at length, a preliminary report has been prepared by ARI which summarizes some of the findings.

The implementation effort took place at four different sites, with three (and at one site--four) weeks of training at each site. Two groups were involved, "A" teams, which came and stayed throughout the entire period, the hypothesis being that their performance would improve as the training weeks passed, and "B" teams, who were changed every week, and were thus expected to be more inexpert and serve a control/baseline function. The relative force ratio of 1:1 was maintained throughout the exercises, each side consisting of a tank platoon, two TOWs, and two Infantry Squads mounted in Armored-Personnel Carriers (APC). The missions assigned were limited to meeting engagements or attack/defense (delay).

The primary objective data in a REALTRAIN exercise are the casualties incurred by both sides in two-sided, free-play exercises. With increases in tactical proficiency it would be expected that there would be changes in the number of casualties which occurred. These changes could come about in two ways. With increasing tactical proficiency, a combat unit should reduce the number of casualties it incurs (by proper use of cover, concealment, suppression, and proper movement techniques), while at the same time increasing the number of casualties it inflicts on the opposing force (by more effective employment of all available weapons).

Meeting Engagements: Figures 1 and 2 show the percent of casualties incurred by Team A (experienced) and Team B (inexperienced) for weeks one and three of training for tanks and infantry. Figure 1 for tank casualties, shows that both teams sustained approximately the same proportion of casualties during the first training week (Team A: 48%, Team B: 45%), as would be expected when both teams have had the same (limited) amount of tactical training.

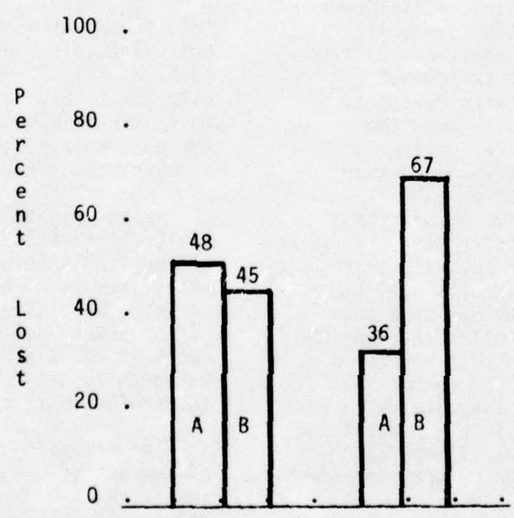

Figure 1. Comparison of Tank Casualties for Team A and Team B Meeting Engagements (N)

There is a large difference between the two teams for the third week; Team A sustained 35.7% casualties, while Team B sustained 66.7% casualties, thus indicating that REALTRAIN does increase tactical unit proficiency over time.

From Figure 2, it may be seen that during the first week of training, Team B lost more infantrymen than Team A (49% vs 34%).

on expert military judgement and are in general agreement with weightings found in other firepower indices. For this WCI a lower value was better; that is, a force sustained fewer casualties itself. The Weighted Casualty Index used was:

WCI = 35 (# tanks immobilized or killed) + 25 (# TOWs killed) + 15 (# APCs killed) + 1 (infantry casualties)

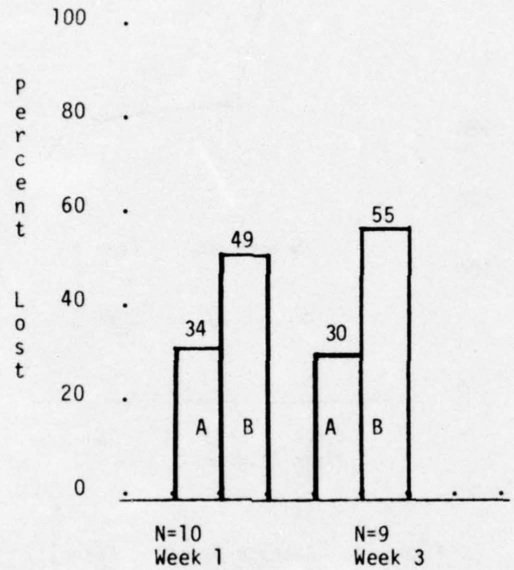

Figure 2. Comparison of Infantry Casualties for Team A and Team B Meeting Engagements (N)

In the third week the A Team reduced its casualties slightly (34% to 30%), while the B Team casualties increased (49% to 55%). The results in terms of infantry casualties are not as clear-cut as they were for tank casualties, although there was a demonstrable performance difference during the third week of training between the two teams. By the third week, the A Teams were beginning "to get it all together"--reducing the casualties incurred on themselves and increasing the casualties inflicted on the B Teams.

The use of a Weighted Casualty Index (WCI) allows diverse categories of data to be integrated into a single measure. In addition, differences in the utility of various weapons systems can be taken into account. The weightings employed are based

Figure 3 presents training effectiveness across all exercises as measured by the Weighted Casualty Index. During Week 1, no difference was observed between the A teams and the B teams, since the two teams had equivalent training exposure, and no difference would be expected.

However, data from the second and third weeks, comparing increasingly experienced A teams with inexperienced B teams, show that performance differences were observed. During the second week, A teams incurred smaller losses than the B teams, and in Week 3, Team A similarly incurred smaller losses than the B teams.

It is interesting to note that a comparison of the WCI for the A Team alone

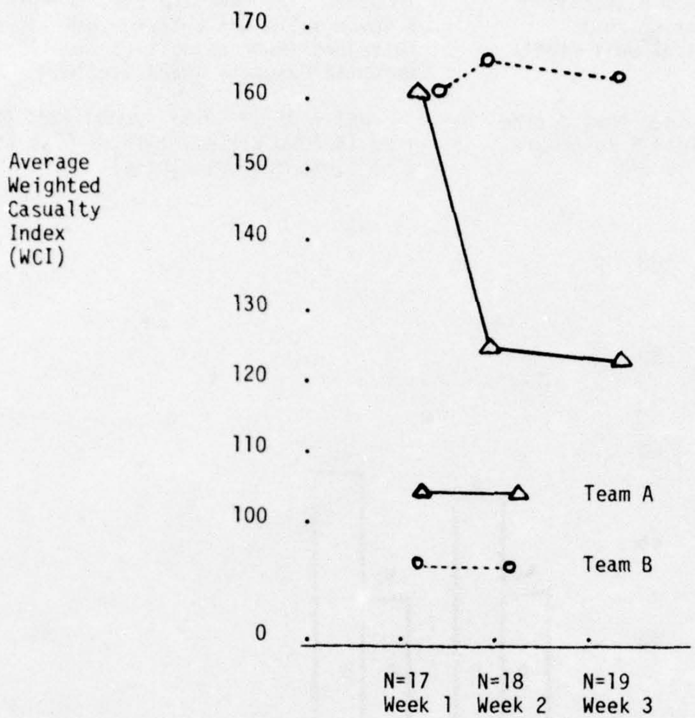

Figure 3. Average Weighted Casualty Index (WCI) for All Exercises (N) by Weeks

for Weeks 1 and 3 shows a significant improvement in overall casualty reduction.

Indirect Fire: Indirect fire data were collected during the play of the exercises for each team. The critical data extracted from the artillery control sheets for this analysis were the number of simulated rounds fired by each team which were then converted into the number of rounds that would actually have been fired.

In reducing the raw data, casualty counts were based on casualties inflicted rather than casualties received. A casualty was defined as a vehicle, vehicle crewman, or infantryman killed or a vehicle immobilized. For purposes of the indirect fire analysis, all casualties were equally weighted. For example, an immobilized tank was equivalent to a destroyed APC or an individual soldier killed. Since there was no way to directly link a casualty to a specific fire mission, it was not possible to analyze indirect fire usage as a function of type of casualty inflicted. Equal weighting of casualties seemed the most reasonable alternative.

Three summary statistics are reported: TOTAL CASUALTIES, TOTAL ROUNDS, and a CASUALTIES/ROUND measure of efficiency. TOTAL CASUALTIES (which are casualties inflicted, not incurred) and TOTAL ROUNDS are found by summing the appropriate figures from all exercises included in the scope of the table. CASUALTIES/ROUND, calculated by dividing the TOTAL CASUALTIES by TOTAL ROUNDS, is a general index of the efficiency of the indirect fire use. Figure 4 summarizes the use of artillery for both A teams and B teams for all the training conducted at all sites during all 54 exercises.

	Teams	Total Casualties Inflicted	Total Rounds	Casualties/ Rounds
All Weeks (N = 54)	A	356	3999	.089
	B	295	5491	.054

Figure 4. *Indirect Fire Analysis*
All Sites/All Exercises (N)

	Week 1		Week 2		Week 3		Weeks 1,2,3	
	Team A	Team B	Team A	Team B	Team A	Team B	Team A	Team B
All Sites								
Initial Detector	5	5	7	3	5	3	17	11
Initial Engager	6	4	9	1	6	3	21	8

Figure 5. Team Making Initial Detection and Initial
Engagement for all Weeks (Meeting Engagements)

	Team A		Team B	
	Initial	Detection	Initial	Detection
	Minutes After Start	Range	Minutes After Start	Range
All Weeks (1-3)	14.4	844.1	15.9	615.5

Figure 6. Initial Detection (In minutes after start and
range) by Team for All Weeks/All Sites

	All Missions	Percent of Total
Tank	9	15.3%
TOW	10	16.9%
Infantry	10	16.9%
Unobserved Fire	17	28.8%
Unobserved Fire	13	22.0%

Figure 7. Weapon Inflicting First Casualty (All Missions)

Overall, Team B fired considerably more rounds than Team A, while inflicting fewer casualties. Again, Team A was consistently more effective than Team B.

In order to determine if there was a relationship between which side initially detected and/or engaged the other and amount of training, this analysis looked at which team was able to detect and engage the other first, how quickly, and at what range. Figure 5 contains the number of times that each team made the initial detection and engagement for meeting engagements. The data are then summed over all weeks and sites.

Initial detection and engagement events were split equally between the teams in the first week. However, in the second week, and continuing on into the third, Team A clearly enjoyed the advantage in detecting and engaging their opponents.

In addition to noting who detected first, the times and distances for these detections were also collected and summarized. Figure 6 shows detection time and range for all weeks and all exercises.

Overall, Team A detected the enemy in shorter times than did Team B. Time equating to distance, as it does in this case, this earlier detection time means detection at greater average distances as Figure 6 illustrates. This greater distance of course translates into more space for small unit commanders to deal with the enemy, and bring into play sooner the increased lethality of all the weapons found on the modern battlefield.

Finally, the data for weapons inflicting the first casualties is displayed in Figure 7.

In summation, it appears as if increased training resulted in an increased ability to detect and engage the enemy first, at least in meeting engagements. The time required to detect the enemy was shorter for the trained (Team A) than it was for the untrained (Team B). The data for weapons inflicting the initial casualties tend to indicate that artillery, particularly preplanned fires, account for the majority of early casualties.

Tank Losses: The results presented up to this point have been related to training effectiveness. The data collected also shows evidence of realistic and credible simulation of weapons effects during the REALTRAIN exercises, thus it is possible to look at the data in terms of weapons effectiveness.

Figures 8 and 9 depict the percent casualties inflicted by each weapon type.

$$\frac{\text{Tanks Killed}}{\text{Tanks Played}} = \frac{219}{539} = 41\%$$

Percent of Kills By:	All Sites
Tanks	51%
TOWs	25%
DRAGON	4%**
90mm & LAW	19%
Grenade	2%

** DRAGON not played at all sites.

Figure 8. Tank Losses as Function of Weapon Type

	Baumholder Large Open Area	Friedberg Small Wooded Area (Heavy Fog)
Tanks Killed / Tanks Played	$\frac{69}{132} = 52\%$	$\frac{46}{139} = 35\%$
Percent of Kills By:		
Tanks	55%	39%
TOW	32%	15%
LAW	4%	9%
90mm RR	9%	30%
Grenade	0%	7%

Figure 9. Tank Losses as Function of Weapon Type

REALTRAIN Compared to:	Live Fire	Field Exercise
is:		
More Effective	77%	97%
About the Same	21%	2%
Less Effective	2%	1%

Figure 10. Comparison of REALTRAIN to Other Methods of Collective Training

Training value of REALTRAIN exercises for a controller as compared to participants:

Equal to or greater than:	86%
Less than:	14%

Figure 11. Tactical Training Value of REALTRAIN Exercises for Controllers

Figure 8 Tank Losses indicate that across all sites approximately 50% of the tanks killed were killed by other tanks, 25% by TOWs and 25% by a combination of weapons in the hands of the individual foot soldier--the Light Anti-tank Weapon (LAW) 90mm recoilless rifle (RR), grenades, and the DRAGON.

Figure 9 shows data from two of the training sites which was amalgamated in Figure 8.

One of the things Figure 9 illustrates is that REALTRAIN provides a simulation of weapons effects and capabilities with face validity. In the large open area with longer fields of fire, the long range anti-tank weapons (tank guns and TOWs) did nearly 90% of the tank killing. On the other hand, when visibility and fields of fire became restricted in the smaller area, nearly half of the tank kills were with short range infantry weapons, LAW, 90mm RR, and the grenade.

No discussion of engagement simulation can be considered complete without some discussion of the acid test of any training system--troop acceptance. For a system to be successful the soldier must believe that he can use it, with confidence, and that its use will benefit him. During post-exercise interviews during the USAREUR REALTRAIN implementation, soldiers, leaders, and controllers were polled on their perceptions about engagement simulation training.

A Leader-Controller Questionnaire was administered to 343 controllers and 38 leaders ranging in grades from E-4 to 0-3. Most respondents were in grades E-6, E-7, 0-1 and 0-2, representing primarily squad and platoon level NCOs and officers.

The questionnaire sought to obtain data about recent unit training experiences (other than REALTRAIN) as well as reactions to REALTRAIN and, for controllers, their reaction to their experience as controllers. Responses were typically quite favorable to REALTRAIN. As Figure 10 shows, REALTRAIN was reported as more effective than live fire exercises and traditional field exercises.

Controllers were also asked about their experiences as controllers. Responses in Figure 11 demonstrate that 86% of controllers feel that the tactical training value of REALTRAIN exercises while serving as controllers was equal to or greater than the value for a participant.

Figure 12 indicates that 90% of the controllers and leaders considered REALTRAIN "very effective" for training in use of terrain for cover and concealment, 73% felt it was "very effective" in training on employment of all available weapons, while 62% felt it was "very effective" in training on employment of indirect fire.

Finally, we turn to the soldiers themselves, those who participated in the tactical exercises. Their acceptance was overwhelming.

A questionnaire was completed by 542 soldier participants; 302 with an infantry MOS (56%) and 240 with an armor MOS (44%). The response to the questionnaire shows no systematic or significant differences in responses among sites, teams, armor versus infantry, or rank of respondent. Therefore, the results presented in Figure 13 discuss the results of all participants without any further breakdowns.

The responses to a question on the perceived state of training before and after participation in REALTRAIN are summarized in Figure 13. The results speak for themselves!

Figure 13 shows graphically that prior to REALTRAIN only 43% felt that they were adequately trained, but that after exposure to REALTRAIN training, 86% felt that they were adequately trained.

Probably underlying the perceived improvement in state-of-unit training is the fact that most participants felt that REALTRAIN provided more effective training than their normal unit training.

When the soldiers talked about REALTRAIN, their universal acceptance was really evident. Said one sergeant:

> "You can see it. In REALTRAIN you see your mistakes and talk about them. Why did I get killed? Why did that TOW see me? How did this infantryman get on top of my track and throw a grenade inside? You can see it and you know your mistakes, and very rarely do you make the same one twice."
> Staff Sgt, Co B, 3d Bn, 32 Armor
> (A Team)

An infantry squad leader commented on the realism and utility of the REALTRAIN engagement simulation system:

How effective do you consider REALTRAIN to be for training units to:

	Very Effective	Effective	Not Effective
a. Use terrain for cover and concealment	90%	9%	1%
b. Employ indirect fire	62%	35%	3%
c. Properly employ all available weapons	73%	25%	2%

Figure 12. Effectiveness of REALTRAIN for Tactical Training

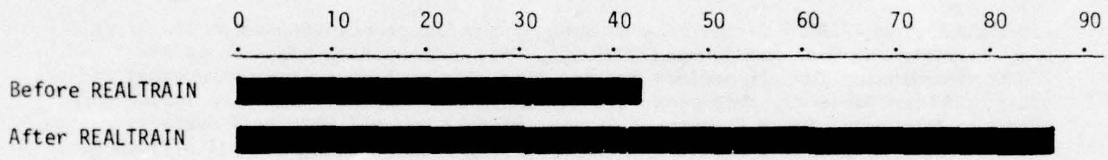

Figure 13. Troop Perceptions of State of Unit Training

"I am a combat vet. Most of the guys out here didn't have any idea about it, not in my squad. But right now they know what's involved and they are keeping their heads down, their tails down, they're moving fast and they're moving right. They are working as teams."

Concerning combined arms tactics this same squad leader said:

"Killing tanks! You want to get the tanks. We found out, the tankers have found out, that we infantry can get those tanks. Once we can get those tanks in the woods we can tear them up; they can get us in open terrain, that's their meat. Staff Sgt, Co C, 1st Bn, 36th Inf (Team A)."

Perhaps, though, the most telling and eloquent comment of all is this one from an armor company platoon sergeant, after 3½ weeks of training.

"I say it's the best training I've seen since I have been in the Army --it just can't be compared with anything else. My men want to stay another month. Since we began training, I've had a total of three sick calls and those were because of the flu epidemic. My appointments are just emergency type things. Accountability and morale is 100 percent. It has been beautiful."

ABOUT THE AUTHOR

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SIMULATION OF A WEAPONS FIRE SIMULATOR MODELED AS AN OPTICAL COMMUNICATION CHANNEL

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SUMMARY

This paper presents a method of simulating various noise sources in a Weapons Fire Simulator System which has been modeled as an Optical Communications Channel. This Weapons Fire Simulator System is composed of laser transmitters mounted on weapons that fire blank cartridges, and laser receivers mounted on targets. The laser transmitter sends out "kill" beam pulses to the target whenever blank cartridges are fired. Detection of these pulses at the target signifies a "hit." The entire system along with the optical communication channel is simulated in a general-purpose computer program called SCEPTRE. This analysis package is an efficient means of modeling the communication channel characteristics and determining signal-to-noise ratios as functions of various electrical and physical parameters. Also the SCEPTRE program is a versatile tool for circuit noise calculations.[1] The main advantage is a single SCEPTRE run computes the total noise output from a large number of noise sources distributed throughout the circuit.

INTRODUCTION

The computer-aided design package SCEPTRE is used to simulate a portion of a Weapons Fire Simulator System.

SCEPTRE is an automatic circuit analysis program that solves for the transient and steady state response of large networks. SCEPTRE solves circuit equations from a description of circuit topology and component values. In addition, a defined parameter mode solves state equations which can describe any system. This approach models the receiver section. The communication channel is modeled using FORTRAN IV subroutines. SCEPTRE's circuit description is composed of elements, defined parameters, and functions. Element values can be defined by evoking FORTRAN IV subroutines. Subroutine parameters can be either circuit variables, defined parameters, or constants. The subroutine facility is used to specify noise sources and atmospheric effects on signal sources. Any of these parameters can be changed via the rerun feature.

A block diagram of the laser optical communication system representing the weapon fire simulator is shown in Figure 1. The laser transmitter emits a digital pulse code whenever the weapon is fired which includes weapon identifying data. The laser beam passes thru an optics system into the communication channel, the atmosphere. The channel characteristics include atmospheric turbulence, scattering, and absorption. These effects cause the laser beam to diverge, bend, attenuate, and scintillate. These effects are a function of the path length and specific meteorological conditions. The direct or indirect sunlight illuminating the laser detectors, cause a constant dc bias in the photodiodes generating shot noise. The signal amplifier generates shot and thermal noise. The output of the signal amplifier feeds digital processing circuitry.

The electrical noise sources in passive and active electronic components have been extensively examined for many years.[4,5] There is an increasing need for computer-aided noise analysis since calculations associated with noise in electronic circuits are often extremely tedious and complicated. In these calculations, noise is superimposed on the electronic circuit as a current or voltage source whose value follows the normal distribution probability curve with its mean value zero and standard deviation a function of various parameters.

The SCEPTRE program is a general circuit analysis program having many active device models available in its "library." One can add the noise sources into the existing SCEPTRE device models for calculations, or the user can supply his own model and do the same.

Noise Sources

The sources of noise encountered are shot noise, thermal noise, and excess noise. The magnitude of the shot noise, having a constant spectral density, can be calculated from physical parameters. We call this type of noise a white noise source. Shot noise is due to the fluctuations of the number of charge carriers flowing through a junction barrier in a solid state device. For a forward biased PN junction photodiode, the spectral density of the current fluctuation

has an expression $Si(f)=2eI$ where "e" is the electron charge in coulombs, and I is the dc current flowing through the photodiode. The thermal noise is caused by the random vibration of the charge carriers in a resistor due to thermal agitation. Over the practical frequency range of a circuit's operation, the thermal noise has a flat spectral density and is considered to be a white noise source. The excess noise most often encountered in electronic circuits is the 1/f type which has a spectral density of the form $S(f)=K/f^b$, where K is a constant and "b" has the value close to unity. The other type of excess noise found in semiconductors and photodiodes is burst noise. This noise consists typically of random pulses of variable length and equal height. Burst noise has a power spectral density varying with frequency in the form of $S(f)=K/f^a$ but with "a" approximately 2. Since both types of excess noise have spectral densities increasing as the frequency decreases, they are dominant noise components only in the low frequency region (below 10 KHz). This analysis deals with high frequencies masking the excess noise with shot and thermal noise. Assume excess noise is negligible and equal to zero for this paper.[2]

The noise sources in electronic circuits are normally represented in the form of voltage and current sources. The above noise sources are two types; one with the spectral density independent of frequency (called white noise), and the other with the spectral density varying with frequency (called colored noise).

Simulation of Noise Sources

Both white and colored noise sources can be simulated by insertion of FORTRAN IV subroutines into the SCEPTRE source deck. The SCEPTRE program is well known for its simplicity and capability for handling the input and output signals of a circuit with time as the independent variable. This capability of the program makes it especially efficient for circuit noise problems because all the noise sources in a circuit can be simulated with current or voltage noise sources which have the required spectral intensity. For this paper, the FORTRAN IV subroutine GAUSS which is available in the IBM/360 Scientific Subroutine Package was used to simulate the white noise sources. The simulation was achieved by using the normally or Gaussian distributed random numbers generated by the subroutine GAUSS as a voltage or current source in the circuit. To use this subroutine, the mean value and standard deviation of the distribution must be given in the program. Set the mean value of the noise to zero since we are interested only in the ac component of the noise. The standard deviation of the shot noise distribution can be determined via the following. Let the time interval between the neighboring randomly generated numbers be Δ and, if the number of the random points generated is large enough, the spectral intensity of the noise source will have an expression

$$Sv(f) = \begin{cases} Sw; 0 < f < \frac{1}{2\Delta} \\ 0; \text{ elsewhere} \end{cases}$$

where Sw is the spectral intensity of the white noise source. For this analysis, only the positive frequency is considered. The mean square magnitude or the variance of this noise can be represented as

$$\overline{V^2} = 3.204 \times 10^{-19}\ If$$

The standard deviation is

$$\sigma = \sqrt{\overline{V^2}} = \sqrt{3.204 \times 10^{-19}\ If}$$

where I is the photo diode current generator JA, or JB thru JD in Figure 3. The time interval Δ is determined by the highest frequency of interest with the maximum frequency of interest being

$$f = \frac{1}{2\Delta}$$

For example; to generate a shot noise source which has a constant spectral intensity from dc up to 10 MHz,

$$\Delta = \frac{1}{2f} = \frac{1}{2 \times 10^7} = 50 \times 10^{-9} \text{ sec}$$

should be used. It is important to note that all the noise sources simulated in this way are uncorrelated, since each photo diode has its own GAUSS subroutine, and contain all the noise power in the usable circuit bandwidth. These subroutines can be simultaneously inserted into the SCEPTRE program to compute the instantaneous values of the noise at the output of the circuit being simulated. From these values of noise, the noise power can be easily calculated by another FORTRAN IV subroutine that performs these calculations.

The thermal and shot noise in the signal amplifier are simulated by using the signal amplifier's measured output noise voltage. Divide this value by the amplifiers gain and use as the standard deviation for the normal distribution. The mean value is set to zero. Assume a noise bandwidth of 10 MHz, then

$$\Delta = \frac{1}{2f} = \frac{1}{2 \times 10^7} = 50 \times 10^{-9} \text{ sec}$$

Transmitter and Receiver Efficiency Factors

These factors are due to the optics at the laser transmitter and receiver. The transmitter efficiency factors lower the

effective laser output power. For a typical laser transmitter the transmitting efficiency is 22% with the receiver efficiency 30%. Thus, the equivalent laser power at the receiver's detectors is a function of the product of the transmitter and receiver efficiency factors.

Simulation of Atmospheric Effects

For the purpose of laser system design, atmospheric effects may be classified as attenuation and turbulence. For the design of a laser for an optical communication link, where the target or receiver is smaller than the laser beam, both attenuation and turbulence effects must be considered.[3] Attenuation in the atmosphere is caused by the mechanism of absorption and scattering. Most lasers have output wavelengths outside the absorption bands which are selected sharp bands throughout the electromagnetic spectrum. Scattering attenuation of a laser beam occurs when the photons in the laser beam are deflected by particles in the air. At shorter wavelengths, the air molecules will cause scattering attenuation, but at longer wavelengths, microscopic particles of dust and smoke are the primary scattering media. At 0.904 microns, attenuation is mostly due to particle scattering. Visibility is also a function of atmospheric attenuation and serves as a convenient parameter for specifying the attenuation. Turbulence effects are caused by refractive index inhomogeneities in the atmosphere and may result in deflection or spreading of the laser beam or in nonuniform energy distribution across the wavefront. All of these effects cause degradation of performance, resulting in reduced energy density on the target or receiver.

Atmospheric Attenuation

A FORTRAN IV subroutine calculates the percent transmission through the atmosphere of the laser beam based upon the path length, and wavelength. The transmission of the laser beam through the atmosphere is given by

$$T = e^{-\alpha R}$$

where α is the attenuation coefficient, and R the path length. This coefficient is a function of molecular scattering, particle scattering, and absorption. For a given wavelength, α is a sum of these factors. Visibility is defined as the range where a target of 100% contrast is seen as a target with its apparent contrast reduced to 2%. An accurate empirical relationship between α and the visibility accounting for the variation of α with wavelength is

$$\alpha = \frac{3.91}{Rv}\left(\frac{0.55}{\lambda}\right)^{g}$$

where "g" is a function of visibility (Rv) which varies according to the following

Rv(km)	g
0-6	$(Rv/5)^{1/3}$
6-9	(0.86+Rv/30)
9-12	(0.98+Rv/30)
12-100	(1.15+Rv/200)

Atmospheric Turbulence

The atmosphere is an inhomogeneous medium made up of regions of varying size in which the refractive index deviates from the mean value. When a laser beam passes through the atmosphere, these regions result in several effects. These effects are beam steering (the entire beam is deflected from its original path), spreading (the divergence of the beam is increased), and scintillation (phase changes across the wavefront result in constructive and destructive interference causing amplitude changes in the wavefront that vary in a randomly distributed Gaussian fashion).

Beam steering is assumed negligible, and beam divergence is a nonprobabilistic function for this analysis. Let the laser output power be PWR, XDIV the beam divergence in the X direction, and YDIV the beam divergence in the Y direction. The fraction of the transmitted energy at the receiver (PRW) is given below:[9]

$$A = (2.54 \times 10^{-2} + XDIV * R)/2$$

$$B = (2.54 \times 10^{-2} + YDIV * R)/2$$

$$EFA = e^{-\left(\frac{xd}{A}\right)^2} e^{-\left(\frac{yd}{B}\right)^2}$$

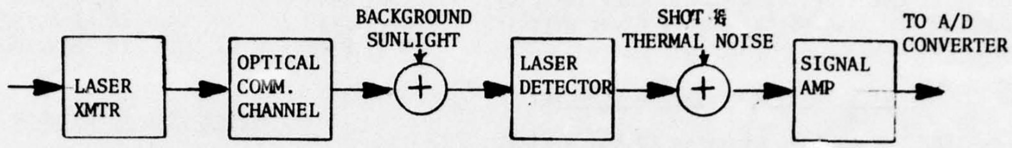
$$PRW = \frac{PWR\ (2.54 \times 10^{-2})^2\ EFA}{\pi\ (2.54)^2\ AB}$$

PWR = POWER * XET * XER
XET = Efficiency factor for transmitter
XER = Efficiency factor for receiver

where R is the path length, Xd the X distance from the laser beam center to the target center, and Yd the Y distance. PRW is the laser beam power at the detector after beam divergence and efficiency factors have been applied to the transmitter and receiver. PWR is the laser power output after efficiency factors have been applied. See Figure 2 for an illustration.[9]

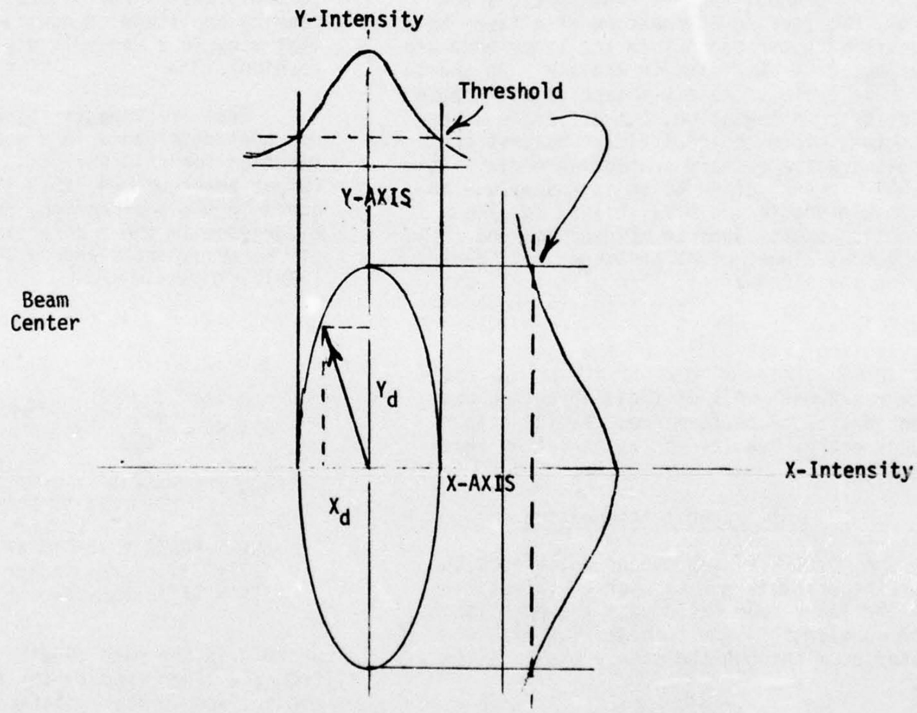
Scintillation Effects

A FORTRAN IV subroutine calculates the scintillation effect simulated by the subroutine GAUSS. Tatarski's work has shown that the intensities in a laser beam cross section are log normally distributed (have



Block diagram of weapon fire simulator
viewed as an optical communication system

Figure 1.



Cross-sectional view of laser beam intensity distribution.
The beam's elliptical cross section is defined by the threshold value,
the peak power and the beam divergence of the transmitter.

Figure 2.

a normal distribution when plotted with the *intensity on a* logarithmic scale), with the variance of the GAUSSIAN distribution being

$$\sigma_t^2 = 1.23\, C_n^2\, K^{7/6}\, R^{11/6}$$

for an infinite plane wave case.[7] Here K is the wave number $2\pi/\lambda$ corresponding to the wavelength being propogated, Cn the turbulence structure constant of the atmosphere, and R the path length. The three classes of turbulence are:[6]

Weak turbulence	$Cn = 8 \times 10^{-9}\ m^{-1/3}$
Intermediate turbulence	$Cn = 4 \times 10^{-8}\ m^{-1/3}$
Strong turbulence	$Cn = 5 \times 10^{-7}\ m^{-1/3}$

During different times of day and seasons of the year, use different turbulence constants. During the winter season, use weak turbulence at sunrise and intermediate turbulence at noon; during the summer season, intermediate turbulence at sunrise and strong turbulence at noon.

One problem with the variance equation is that it predicts an infinite increase of *energy variance with respect to path length*, which is not the case. One must assume that σ_t will saturate at some level a function of both path length and σ_t^2 . The corrected value of variance is

$$\sigma_a^2 = \ln\,(2 - \exp(-\sigma_t^2))$$

which saturates at 0.6931, the natural log of 2.[8] This equation is valid for a spherical wave but another correction is necessary for a plane wave. In our case, with the beam divergence high (> 3 milliradians) assume the laser is emitting a spherical wave with no correction necessary.

The mean value of the normal distribution that SCEPTRE generates is

$$mv = \ln\,(PRW*200*10^{-9}*e^{-\sigma a^2/2})$$
where $200X10^{-9}$=*laser pulse length*

The frequency of the amplitude modulation due to scintillation is determined by eddy wind currents in the atmosphere. This movement of air normal to the path of propagation causes amplitude *modulation of the* scintillation pattern. The maximum frequency of this modulation is determined by the following equation

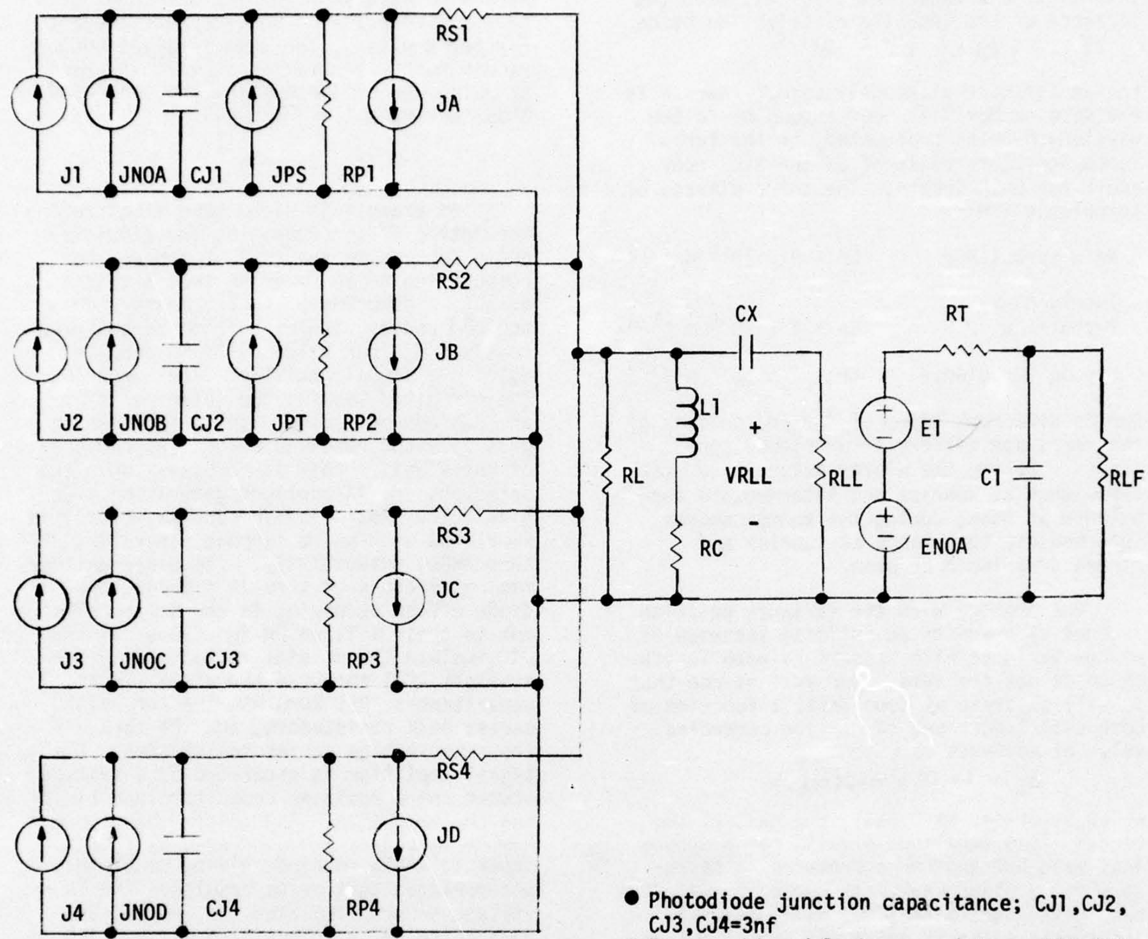
$$f = \frac{Vn}{(\lambda\ R)^{1/2}}$$

where Vn is the component of wind velocity normal to the line of sight, λ the wavelength, and R the path length. This *maximum* frequency is a measure of the rate that turbulence statistics change as the atmosphere moves across the laser beam path. This serves to establish the validity that each transmitted pulse is an independent event. For our analysis, the time interval between random number generation is 1/f, the rate at which new random numbers are generated by GAUSS during the SCEPTRE run.

Example

An example is given here illustrating the method of incorporating the simulated noise sources in the SCEPTRE program to compute the noise power at the circuit's output, a function of the parameters described above. The circuit to be analyzed consists of four solar cells in parallel driving a signal amplifier, *see Figure 3.* The circuitry loading the solar cells is ac coupled and loaded with an inductor to pass only the received pulses (ac component) of the signal. This is necessary when the detectors are in sunlight generating a dc bias. *The shot noise in each solar cell* is simulated with noise current generators JNOA thru JNOD, respectively. The dependent current generators JA thru JD simulate the diode effect occurring in the solar cells due to their silicon PN junction. J1 thru J4 simulate the dc bias introduced by the sunlight, CJ1 thru CJ4 the diode junction capacitances, RS1 thru RS4 the internal series bulk resistances, and RP1 thru RP4 the reverse bias series resistances. The signal amplifier is simulated by a voltage source and a resistor capacitor load limiting the bandwidth. Four different random number sequences are generated by four separate GAUSS routines giving completely uncorrelated shot noise results. The ENOA voltage source simulates the thermal and shot noise of the signal amplifier. JPS and JPT are the current sources simulating the currents due to the received laser pulses. For this analysis, assume a configuration with all four detectors in full sunlight, but only two of them receiving the laser pulses. Resistor RT simulates the output impedance of the signal amplifier with C1 and RLF a low-pass filter simulating the actual bandwidth of the amplifier. The RC time constant gives a *cutoff frequency of* approximately 1 MHz.

One computer run with SCEPTRE and the FORTRAN IV subroutines calculates the noise power at the output with JPS and JPT set *equal to zero* (no signal). Another computer run calculates the average peak signal by setting JNOA thru JNOD and ENOA to zero. These runs are compared and the signal to noise ratio determined. The various parameters discussed in this paper can be varied from run to run with the signal to noise ratio determined as a function of these parameters.



This is the equivalent circuit of four parallel solar cell photodiode outputs applied to an amplifier through a filter. The following is a description of the circuit parameters:

- Transmitter laser power; 5 watts
- Laser pulse width; 200 nanoseconds
- Laser signal current in photodiodes; JPS,JPT Due to scintillation, the laser signal has a statistical variation and for both JPS,JPT; mean value = m_v standard deviation = σ_a
- Current generated due to background illumination; J1,J2,J3,J4
- Current through PN junction of solar cell photodiode; JA,JB,JC,JD
- Shot noise current generated due to current through PN junction; JNOA,JNOB,JNOC,JNOD mean value of noise=o standard deviation=σ
- Photodiode junction capacitance; CJ1,CJ2, CJ3,CJ4=3nf
- Reverse biased leakage resistance;RP1,RP2, RP3,RP4=2KΩ
- Series resistance due to intrinsic bulk material of the photodiode and the circuit loads; RS1,RS2,RS3,RS4=14Ω
- Damping resistance for control of transient response: RL=1KΩ
- Inductance to reduce dc current through PN junction of photodiode; L1=3mh
- Resistance of inductance; RC=0.5Ω
- Coupling capacitor CX=.2μf
- Load resistance; RLL=200Ω
- Amplified signal voltage; E1=100VRLL
- Noise voltage in amplifier; ENOA mean value=o standard deviation=2.7volts
- Internal series resistance of amplifier; RT=1Ω
- Parallel capacitance and resistance used to simulate the amplifier bandwidth; C1=1μf RLF=200Ω

Figure 3.

For a 5-watt laser, the results of these runs are shown in Figure 4. Sun currents J1 through J4 are functions of the receiver optics, visibility, and orientation of the detectors with respect to the sun. Assume one orientation for all computer runs. The laser beam is attenuated by the transmitter and receiver efficiency factors, and subject to the atmospheric channel effects. The beam irradiates two of four detectors. The signal-to-noise ratios plotted represent peak current to rms noise current values. No consideration has been taken as to the effect of visibility on sun current.

Pulse detection occurs if the peak value of the signal current generated by the laser pulse exceeds a predetermined value or threshold. The threshold setting also determines how often a noise spike will be incorrectly interpreted as a pulse. The probability of this occurring is called the probability of a false alarm. The higher the threshold, the less likely a false alarm, but also less likely is the probability of a pulse being detected. Figure 5 shows the probability of detection, P_d, versus sun current, range, visibility and threshold level. The threshold to noise ratio, T/N, can be set to any desired value, and determines the probability of false alarm, Pfa.[3]

DISCUSSION

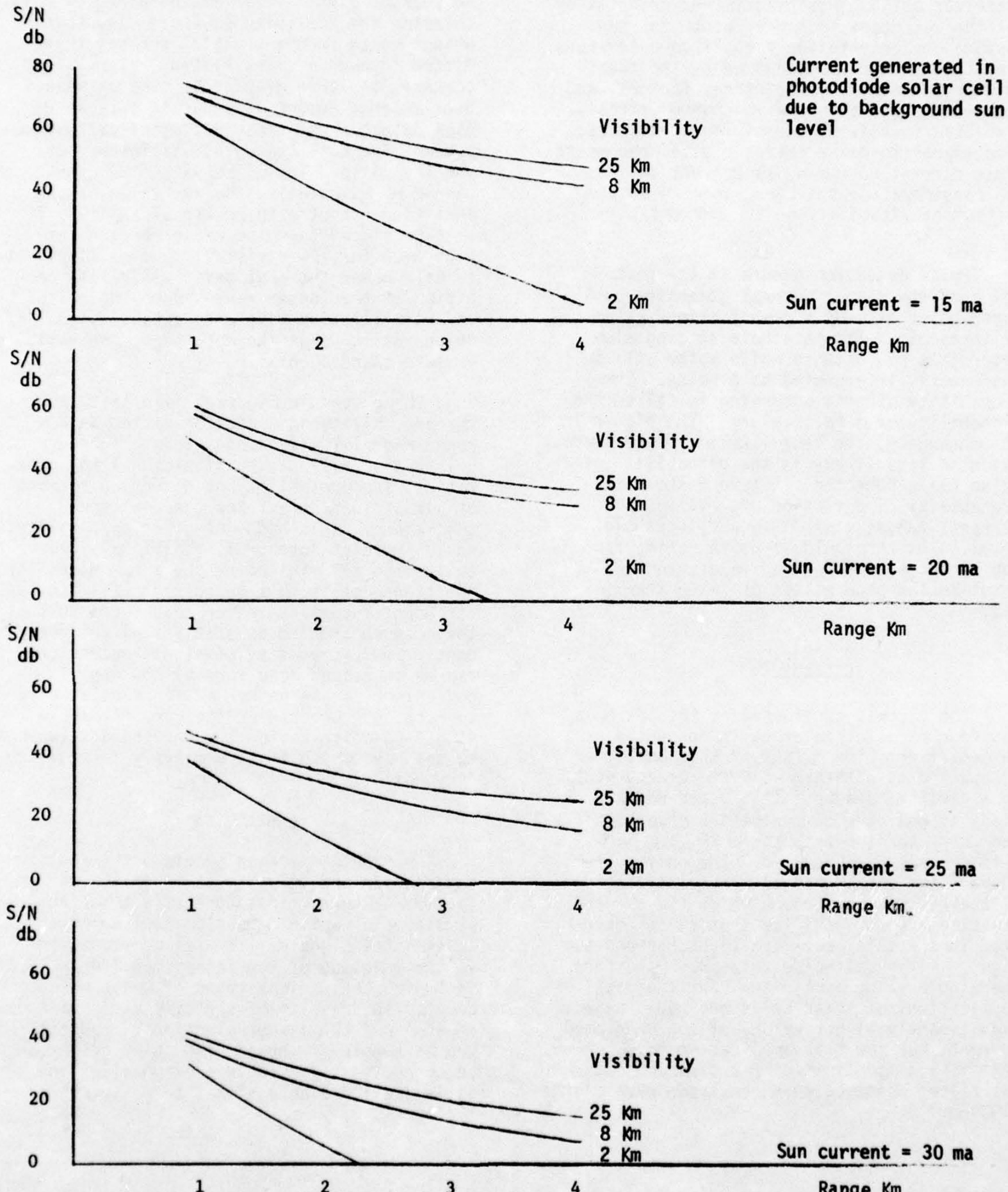
The circuit considered in this example was four parallel solar cells connected to an amplifier. The output of this amplifier is applied to a threshold detector and sent to a digital decoder. This paper was a study of only the communication channel and the detectors, hence, an ideal threshold detector has been assumed. The only system degradation considered is the scintillation of the atmosphere through which the signal traveled and the additive shot noise generated in the solar cell due to background sun light. A typical noise value was used for the single stage amplifier. For the usual applications of solar cells one would expect significantly higher values of sun generated current, but for this application this current is assumed limited by a passband optical filter centered upon the laser wavelength 0.904um.

Figure 4 shows the variation of the average signal-to-noise ratio for various amounts of sun current generated shot noise. An average signal value was obtained by calculating the amplifier peak signal output when a pulse from a 5 watt laser was transmitted through a scintillating, attenuating channel, and then averaging the peak values over a large number of separate pulses. Each detector was treated statistically independent for both the scintillation effects and the noise. The noise values were obtained by calculating the rms value of the amplifier output with no signal applied. The average signal-to-noise ratio remains very high even for lower visibility conditions. It is only under the most sever visibility condition at the longer ranges does the noise and scintillation give unacceptable signal to noise ratios. For the most part, the ratio is more than acceptable.

The graphs in Figure 5 illustrate how the probability of detection varies with range and visibility conditions. These graphs also reflect the high signal to noise ratio. The probability of detection remains at almost 100% except for the most adverse conditions. This high-detection probability would increase further if additional solar cells were illuminated by the same pulse. The additional cells must be spaced sufficiently far apart (usually greater than 8 cm) so that they can be treated as statistically independent. The probability of signal detection can be increased even more by the use of coding for single and/or multiple pulse error correction. Because of the very favorable signal-to-noise ratio, the threshold value can be set high which in turn makes a false alarm very unlikely.

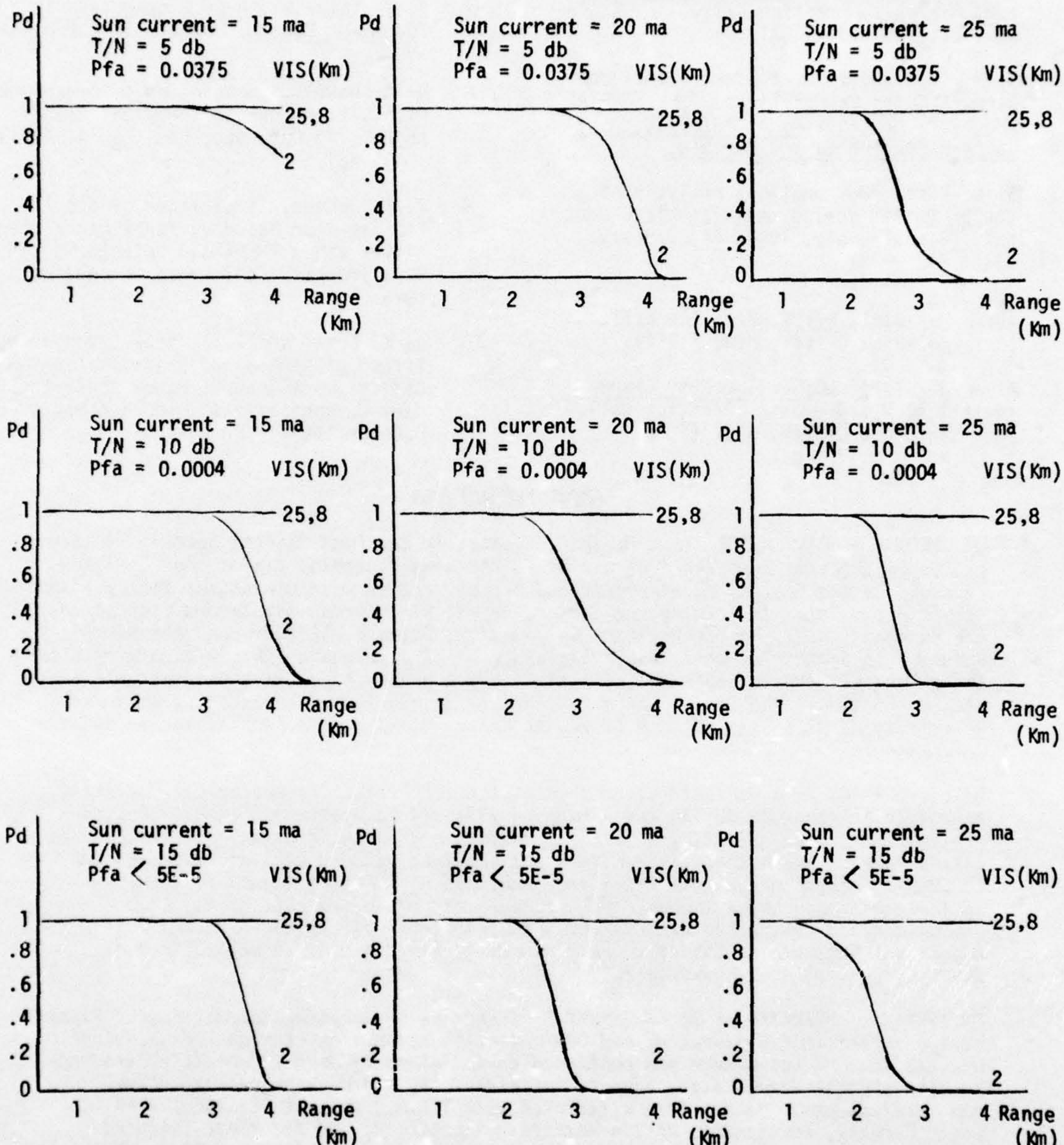
CONCLUSION

The SCEPTRE package provides the ability to describe analytically, through the use of FORTRAN IV subroutines, the effects of an atmospheric communication channel on laser transmitted signals. It also provides ease in the modeling of the laser signal detectors including the various types of noise which occur. The results of the simulation of the channel and the sensor electronics suggest that a number of inexpensive solar cells can be connected to a single pre-amplifier and still provide viable signal to noise characteristics.



The above curves show the variation of average peak signal to noise ratio as a function of visibility and range. For all the above cases the scintillation value was taken to be the worst case saturated value Ln 2, for a divergent laser beam.

Figure 4.



The above graphs give the probability of detection, P_d, of a single pulse as a function of range. Three visibility conditions are shown, the saturated scintillation condition is used for all cases. Reading from left to right, the sun background generated increases while the threshold to noise ratio is held constant. From top to bottom the sun current is fixed while the threshold to noise ratio is increased.

Figure 5.

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TANK DRIVER AND TANK GUNNER TRAINING SIMULATORS

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INTRODUCTION

We are witnessing a growing interest from utilizers in classroom training for tank crews. Simulators exist, or are being developed, which provide efficient training. The purpose of this paper is to specify the concept of tank crew training and to isolate the functions of each new member, in order to better define the features of the simulators to be used for their training.

Analysis of the interworking of the members of a tank crew shows that coordination is provided entirely by the tank commander; there is practically no direct relationship between the gunner and the driver. It is true that their actions are coordinated - reducing speed, or taking up a suitable firing position - but the information, especially visual, which they individually use and the actions they undertake are either totally independent or only slightly correlated. Tank crew training can thus be broken down into independent and specialized phases.

- Training of the driver who receives orders and comments from the tank command

- Training of the gunner whose role generally overlaps with that of the tank commander.

The function of the loader can be neglected at this stage; it is a very simple function and does not require the same training resources. Simulators have been developed for driver and gunner training. Their principles are described below.

DRIVING SIMULATOR

The driving orders given to the driver result from the tank commander's analysis of the near and distant situations. For this, the commander must be given a wide field of view.

Driving orders are simple orders which define:

- the rallying point
- the speed, fast or slow
- if necessary, the path to be followed.

The driver carries out these orders using the near field of view. Except for giving new orders, the tank commander takes little part in the driving process. The driver is responsible for carrying out all orders received; he has considerable independence of action. This is important for defining the student/instructor relationship in the simulator.

The conditions for good driving are as follows:

- Good practical knowledge of the vehicle. The driver must use the vehicle to the best effect in all circumstances, even in the event of malfunctions. The simulator - and this is an inherent feature of all training simulators - must faithfully reproduce the behavior of the vehicle. This implies good reproduction of driving forces and good modeling. The rest is conventional.

- Good situation appraisal. Note that situation appraisal is obtained almost exclusively from visual sources; obstacles, road bends, terrain difficulties, judgement of distances are often appreciated from visible details. Visual representation of the terrain must therefore be of high quality. A closed circuit television system is used, servo-coupled to the driving controls and filming a 1/300-scale terrain model (figure 1). It is important that the model is rich in details. The image display must allow driving in the head-up or head-down position.

- Correct translation of the orders received into driving commands which take the visually perceived terrain difficulties into account. The effects of driving action are perceived in two ways:

  a. The effects of driver actions alone; acceleration, deceleration, steering. These effects are produced by movement of the image, movement of the platform, and by sound effects.

  b. The effects due to terrain irregularities; these are foreseeable effects whose origin is not the driver but whose amplitude is strongly dependent on driving conditions. It is absolutely essential that these disturbing effects be correctly simulated for the driver to obtain the same response from the simulator that he would obtain from the vehicle. He can then appreciate, by being subjected to them himself, the strains his driving imposes on the vehicle - especially during rough driving battle conditions.

The cabin motion system must have good dynamic characteristics and a large angular excursion in the pitch axis. The most important disturbing effect is the elevator effect caused by pitch motion and due to the driver's station being forward of the center of rotation. This effect is obtained in the simulator by placing the cabin forward of the pitch rotation axis of the platform (figure 2).

Instructor's role

The simulator instructor can take the part of the tank commander.

● He will give driving orders. The simulator instructor is given the same information he would have in a real tank (figure 3):

a. The same scene as viewed by the driver; repetition of the trainee's TV picture at the instructor's station.

b. Knowledge of the terrain which would possibly be obtained in a real tank from a panoramic observation of the terrain; a 1/10-scale map of the terrain model, on which the tank's position is continuously displayed, allows the instructor to give general driving orders ("Follow the road for one mile"), or particular orders, which could result in reality from a change in a battle plan ("Turn right, off the road"). It is important that the instructor has the information he needs to be able to give driving orders in good time. The terrain map gives him this advance information.

● He will comment on the driving. A repetition of the image seen by the driver and of the main driving instruments (speedometer, rpm counter, etc.) allow the instructor to comment on the trainee's actions. Using a set of dual controls, he can even demonstrate correct driving technique by driving the simulator from the instructor's station.

Automatic evaluation

The simulator digital computer can also be used to provide automatic evaluation of the trainee's performance. This type of evaluation must be based on a number of criteria selected with the user's approval. The available computing power is sufficient to allow appropriate weighting of each evaluated parameter.

GUNNERY TRAINING SIMULATOR

The gunner's functions and their overlap with the tank commander's functions vary considerably depending on the type of tank and on Army procedures.

However, it is possible to define the main functions of a gunner and the characteristics which a gunnery training simulator should possess.

The most important functions are:

● Operating knowledge of the weapon control system

● Visual situation appraisal and identification of the target designated by the tank commander

● Aiming at mobile targets

● Shooting and observation of the shot in an extremely disturbing environment

● Correction of aim and further shooting.

Use of the weapons system

The gunner's station is faithfully reproduced. The most important features concern:

● The sighting head; field of view, magnification, various reticles

● The aiming controls; play, thresholds, efficiency.

The gunner's station, which is subjected to the shock of simulated recoil, must be rigid. Uncoupled from the image generating system, it can be replaced by the gunner's station for another type of tank, giving the simulator considerable versatility.

Visual situation appraisal

Shooting at a distant moving target is difficult. The simulator must provide this type of training. Identification by the gunner of the target designated by the tank commander requires a high quality image.

A combat environment can be created by a "photo quality" image and by a target moving realistically in a realistic landscape. The representation of an aggressive target trajectory must be able to induce apprehension in the trainee and the desire to neutralize as quickly as possible the enemy who is taking advantage of the countryside (hollows, thickets) to create a dangerous situation.

Aiming - Rangefinding

The main difficulty in this phase is due to target mobility. Movement of the target over the terrain - track and speed -

must be modifiable by the instructor to avoid trainee familiarity and to grade the exercise difficulties to the trainee's ability to overcome them.

It is important that sighting and tracking errors are quantified in the simulator.

Shooting - Observation of results

The main objective of the simulator in this phase is to teach the trainee to disregard the perturbations accompanying shooting:

- recoil
- noise
- hot air
- smoke,

and to observe the tracer and the impact to be able to correct the following shot.

The classroom simulator is superior in its ability to simulate the disturbing environment which is one of the important difficulties of this phase of training. The trainee must overcome this difficulty before he fires his first real shot.

The shell trajectory is accurately simulated and includes the following effects:

- environmental effects; external temperature, wind, etc.
- weapon effects; dispersion, barrel wear, etc.

Instructor's role

The instructor can take the part of the tank commander in three essential phases:

- Target designation. As the instructor himself selects the sequences - type of target, initial position in range and bearing from the tank, type of course - he can then take the following action depending on the Army procedure:
  - Bring the weapon to bear and designate the target or,
  - give the gunner the orders and information allowing him to bring the weapon to bear, identify the target, and shoot.
- Tracking and shooting at a moving target. The instructor has a repeated display of the picture seen by the gunner; the landscape, the target, and the reticles. He is therefore in a position to comment on the trainee's actions at any time. His assessment of performance is supported by a quantified indication of the gunner's errors with respect to the ideal aim.
- Post-shooting commentary. The instructor bases his comments on information obtained from two sources:
  - The repeated display of the picture seen by the gunner.
  - Display of the aiming error and impact error memorized by the computer.

The gunner therefore receives the same directives and comments from the instructor that he would receive in reality from the tank commander.

Instructional aids

The simulator uses a digital computer. All effects (trajectory, masks, etc.) are computed.

Data are thus available to give the instructor the following information:

- numerical readout for the three most important parameters; the time taken by the trainee to effect an operation, aiming error, and impact error.
- exercise evaluation aids; display of the ideal aiming axis, freeze of the shell at the point, for example, where it passes through the vertical plane containing the target.

The simulator can also be used to provide automatically an objective assessment of trainee performance; all the necessary parameters exist and the computing power is adequate.

CONCLUSION

The simulator designs described above are fully suited to efficient classroom training of the driver and gunner. Each can be trained in his own function and get the same assistance (orders and advice) from the instructor as he would from his tank commander.

For loader training, a very simple special-purpose trainer would be quite adequate.

Training of the tank commander in his full command function must cover not only his relation with the other crew members but also, and above all, the tactical situations he will face. Simulation of these situations would require an evolving, complex display including:

- a wide angle of view including both near and far fields

- multiple targets so that the risk from each can be assessed

- friendly vehicles so that the support potential of each can be assessed.

At the present time, it is considered that classroom simulators, although particularly cost-effective for training drivers and gunners, are less cost-effective for training tank commanders.

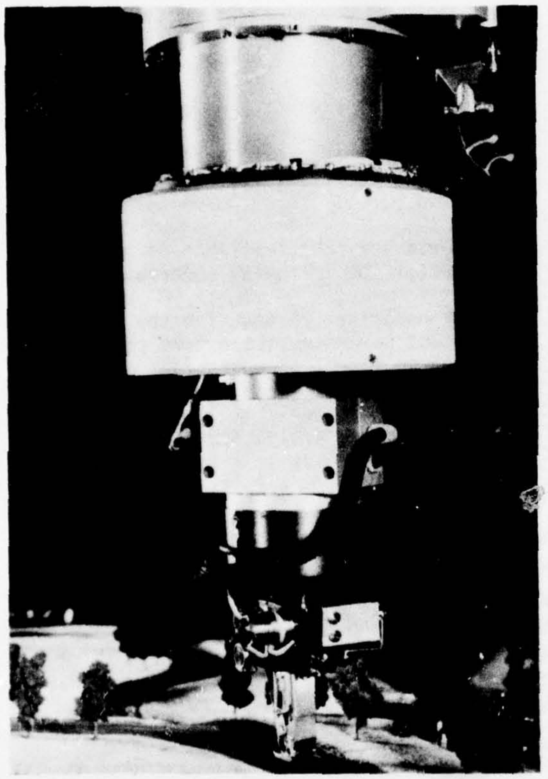

Figure 1. Visual system - Optical probe

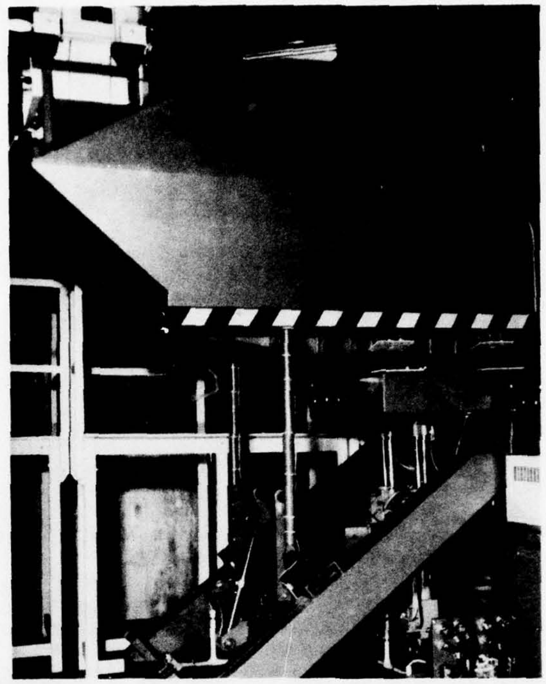

Figure 2. Cabin motion system

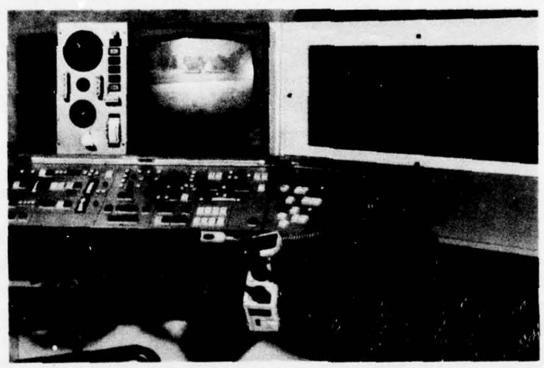

Figure 3. Instructor's station

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WIDE-ANGLE SCANNED LASER VISUAL SYSTEM

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INTRODUCTION

An experimental investigation is being conducted to determine the feasibility of using scanned lasers to generate and display real world scenes for military training applications. The technical objective is to provide high resolution tactical scenes over a continuous wide field of view.

The US Army and Air Force are supporting the development of a breadboard laser camera and display system to investigate the capability of the system and applicability of this approach to military training requirements. Completion of the breadboard system is scheduled for third-quarter 1978.

The prime contractor is American Airlines Incorporated. Redifon Flight Simulation Limited, as subcontractor, is conducting the main body of the work, and the Sira Institute, England, is providing expertise on optical and electronic systems.

Image Generation

Before considering the complete scanned laser visual system, the basic principle of the image generation system will be described with comparison to a conventional television system. The basic components of a conventional television system are illustrated on the left side of Figure 1. The object to be televised is illuminated and the reflected light, over a field of view set by the lens, is picked up by a television camera which generates a video signal for viewing on a picture monitor. The signal is generated as the electron beam in the television pickup tube scans the target in raster format.

On the right side of Figure 1, the same object is scanned by what may be called a laser camera. The laser camera projects a laser beam, scanned in raster format, onto the object. The video signal is generated by a photocell placed where the lamp was placed in the conventional television system.

There are several important points that should be noted in this comparison. Perhaps the most important point is that exactly the same image appears on both picture monitors. This is true as long as the generating and reproducing scanning processes are synchronized and the field scanned by the laser beam is the same as the field of view of the television camera.

Second, the point of perspective or viewpoint with the laser system is the point from which the scanned laser beam leaves the laser camera and not the photocell. Movement of the laser camera produces normal perspective views just as if it were a normal television camera.

Third, lighting effects can be achieved with appropriate placement of photocells. Just as in a conventional model board visual system, where multiple lamps are used to evenly illuminate a terrain model, so in a scanned laser visual system multiple photocells can be used to produce a scene that appears to be evenly illuminated. A concentration of photocells can be used to generate directional lighting effects and fiber optics with photocells behind the model can be used to generate cultural lights.

Now that the basic principle of image generation has been established, the complete scanned laser visual system will be discussed.

Laser Visual System Description

Figure 2 illustrates the complete scanned laser system. As in a conventional camera modelboard visual system, the gantry moves the laser camera in x, y and z coordinates along the simulated flight path over the terrain modelboard. Instead of a lamp bank, there is a small number of photomultipliers which collect the laser light reflected from the model.

The laser camera uses two high power ion lasers, an argon laser to provide green and blue primary colors, and a Krypton gas to provide the red primary color. The output beams from the lasers are combined and fed through flexible fiber optics to the laser camera.

The laser camera contains line and frame scanners which scan the beam in a raster format with the scanning lines running vertically. In the preferred system about 4400 vertical scan lines are used in an interlaced scan. The probe from which the light is emitted is slender,

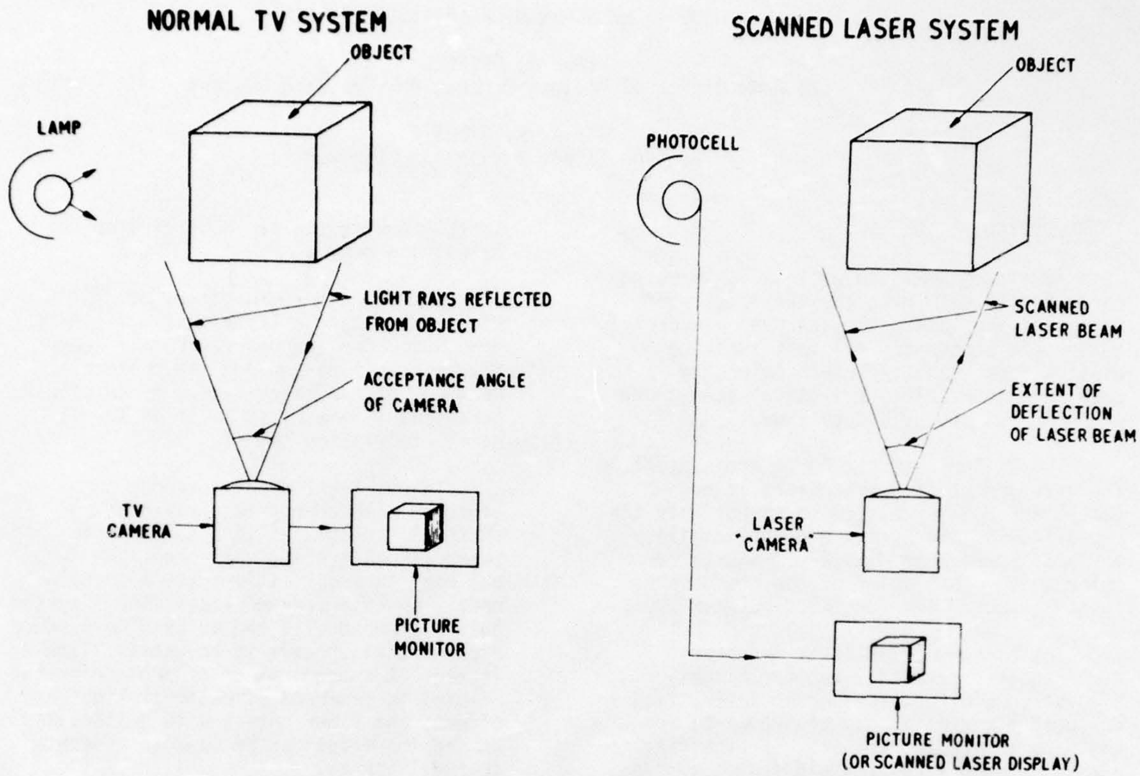

Figure 1. Comparison of Normal and Scanned Laser Television Systems

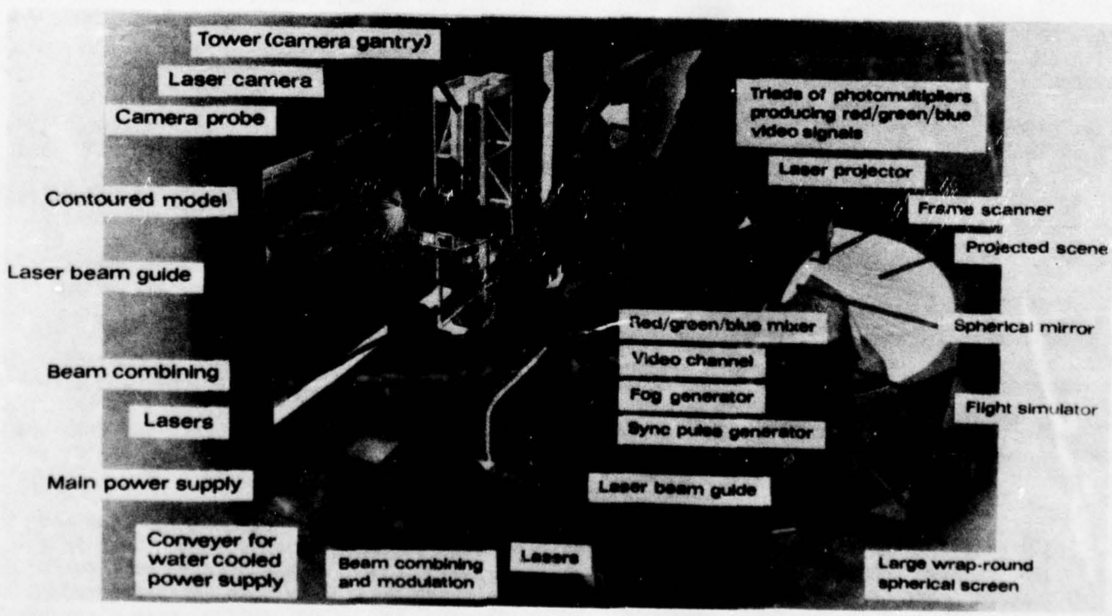

Figure 2. Scanned Laser System for Visual Flight Simulation

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allowing close approach to the terrain model surface and between vertical features on the model.

The photomultipliers are arranged in groups of three, or triads; one of each triad sensitive to red light, one sensitive to blue, and one to green. All the red signals are summed, as are the blue and green, to produce red, blue and green video signals. The video signals are processed with blanking, gamma correction, aperture correction, etc., and fed to the display.

At the display, the three primary color beams again are generated by two lasers, but before being combined, the beams are modulated by light modulators driven by the video signals. A flexible fiber-optics light guide is used to convey the composite modulated beam to the laser projector. The projector uses line and frame scanners, accurately synchronized to those in the laser camera, to project the desired scene.

Since it is necessary to project the beam onto the spherical screen without distortion, direct projection cannot be used as the projection point cannot be coincident with the pilot's head. Accordingly, as illustrated in Figure 3, the emerging beam is reflected first from a spherical mirror, giving overall correct display geometry in the wide-angle, high-resolution image.

Field of View and Resolution

The video bandwidth in the system can be 100 MHz rather than 5 MHz for a broadcast type closed-circuit television system. Therefore, approximately twenty times as many picture elements can be generated and displayed as with normal television. Various tradeoffs are possible between field of view and resolution; the higher the field of view the lower the resolution and vice versa.

Based upon current military training requirements and reasonable development goals, a 175 degree by 60 degree field of view was selected for the experimental breadboard model. With this field of view and a 100 MHz video bandwidth, a resolution of 5 arc minutes should be achieved.

Optical Layout

In order to cover a 175 degree field of view on the model board, the frame scan is accomplished by rotating the frame scan prism from which the laser beam emerges about an axis normal to the model surface. This means that the field angle to be relayed through the scanning probe is 60 degrees rather than 175 degrees, and fairly conventional optics can be used. The principle of the scanning probe is illustrated in Figure 4.

The basic principle of the complete wide-angle scanning system involves passing the laser beam, containing red, blue, and green components, through a line scanner which uses a rotating mirror drum to deflect the beam in a sawtooth deflection approximately 132,000 times per second. The deflected beam is then passed through a derotation prism and a wide-angle lens which expands the vertical angle to 60 degrees. Finally, the beam is deflected by the rotating frame scan prism to emerge as a raster of approximately 4400 vertical scan lines. The derotation prism runs at one-half the speed of the final prism, to keep the scanned line vertical as the final prism rotates. Using a single frame scan prism would produce a 360-degree frame scan, but a nominal 180-degree scan is obtained by using two prisms. To allow for a small percentage of dead time during which the black level of the video signals is established, the actual horizontal field of view will be 175 degrees.

At the end of each 180-degree rotation of the prisms, the line scanned beam has to be switched rapidly by a galvanometer mirror between these two prisms so that the emerging beam is always in the forward direction. This process of changing the beam from one prism to the next inverts the line scan so that the beam deflected by the galvanometer has to be taken through a further prism for correction.

The optical layout in the projector is similar to that of the probe as far as the line and frame scanning processes are concerned. As mentioned earlier, the emerging beam, covering 175 degrees by 60 degrees, is directed first onto a spherical mirror and then onto the spherical screen for viewing by the pilot. The display layout is illustrated in Figure 3.

Roll, Pitch, Heading

The next aspect of the system to be considered is attitude control. In a conventional camera model visual system, the optical probe has servo-controlled optical elements to change pitch and roll, and the complete lower part of the probe structure is usually rotated about an axis normal to the model surface to provide heading changes. With the laser probe, the prisms from which the beam emerges are already rotating continuously. By altering the phase of this rotation at the probe in relation to the corresponding rotation at the display, heading changes can be simulated.

In order to allow close approach to the model surface and easy passage between obstacles, simulation of roll and pitch

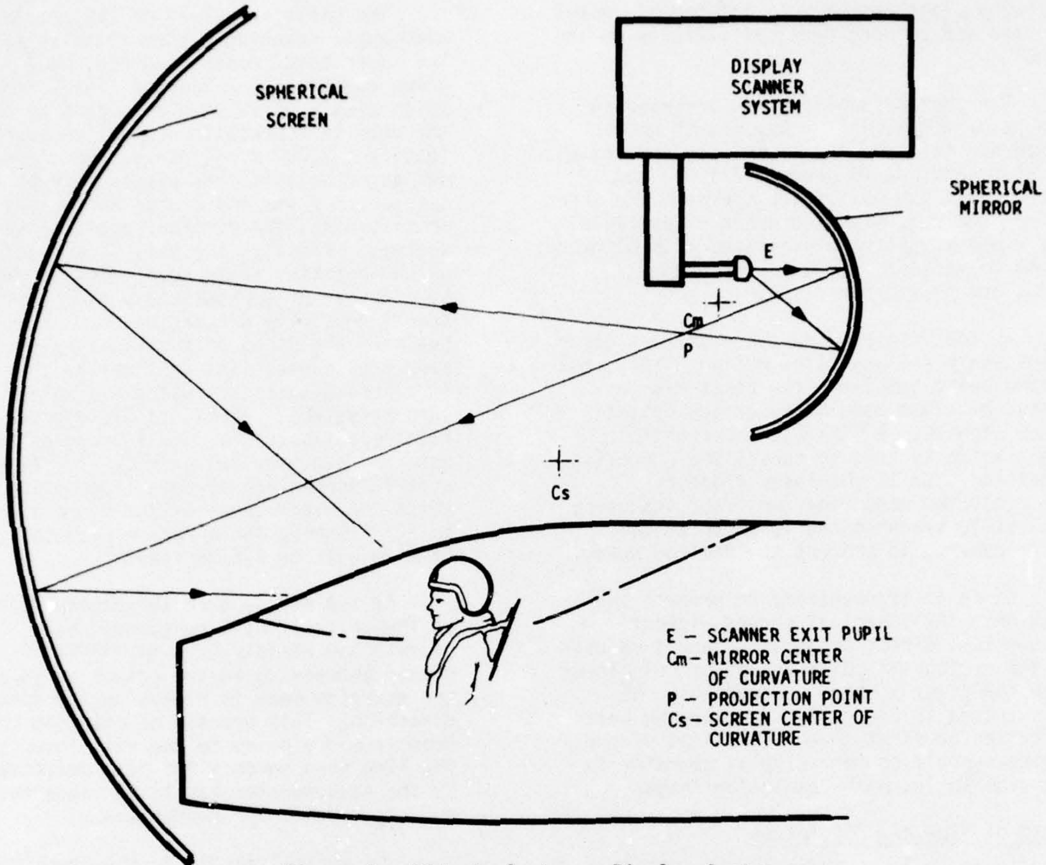

Figure 3. Wide-Angle Laser Display System

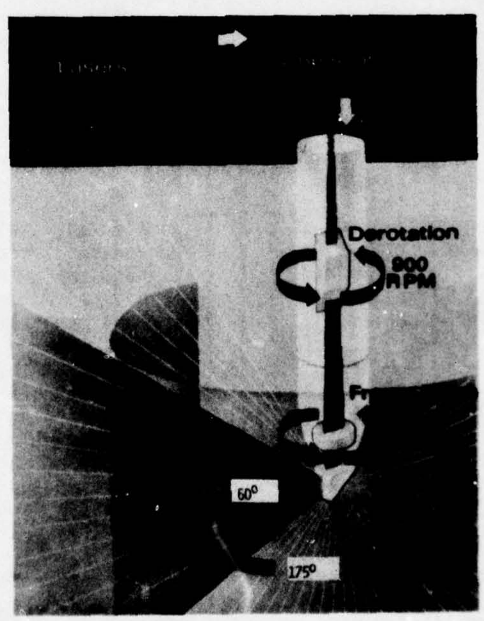

Figure 4. Principle of Wide-Angle Laser Probe

at the display is preferred. There is plenty of room at the display for the mechanisms necessary to achieve this, as shown in Figure 3.

There are several advantages of simulating roll and pitch at the display. First, objects that appear within the vertical field of view continue to be displayed during pitch maneuvers since the entire display format is pitched; Second, targets are not lost off the top or bottom of the screen during roll maneuvers since the entire display format is rolled; and third, it is not necessary to waste television scanning lines in reproducing blank sky. The sky can be simulated with an auxiliary optical projector attached to the main projector.

The primary disadvantage of simulating pitch and roll at the display is that an area of terrain beneath the aircraft cannot be viewed at any attitude and parts of this dead area appear under extreme conditions of roll or pitch.

Focus

The next aspect of the proposed scanned laser system to be considered is that of focussing the beam on the terrain model. Focussing of the beam on the display screen is constant and presents no problem.

Depth of field is a very important consideration in conventional camera model visual systems. The optical probe attached to a conventional television camera has an entrance pupil whose size determines the depth of field in which objects will appear to be in sharp focus. The larger the aperture the worse the depth of field, but the smaller the aperture the more the resolution is limited by diffraction.

With the laser system, in which the scanned laser beam leaves an exit pupil to strike the model, the same basic tradeoff exists. The laser system has the advantage, however, that the laser beam can be put through any chosen aperture. This is unlike the conventional camera model system which needs a minimum aperture to get enough light through for a noise-free picture. Another significant advantage of the laser system is that only one spot on the model is illuminated at a time. Therefore, changes of focus and aperture can be accomplished during scanning to give optimum results. By contrast, within a conventional camera model system, the whole field of view is continuously imaged and techniques to improve the depth of field must operate on the whole field at once.

Two main types of focus correction may be used in the scanned laser visual system; the choice depends on the visual mission. For missions where the modelboard may be considered to be flat for focussing purposes, the tilt lens techniques used for conventional television optical probes may be adopted. An analysis shows that good results will be obtained by using a high aperture tilt lens in the optical system such that the beam is focussed at a short distance when it scans the near part of the model and at a greater distance when it scans the far parts. The absence of roll and pitch motions in the probe makes the design easier.

For missions where the model board can not be considered to be flat, the instantaneous focus may be changed dynamically to give optimum focus for each object struck by the scanning beam.

The technique for carrying this out is to use electrooptic cells to vary the width and convergence of the laser beam before scanning. At the exit pupil of the laser probe the emerging beam is rapidly focussed on the object being scanned and the width of the beam is varied to change the depth of focus.

Figure 5 shows the laser beam passing through an electrooptic cell. The control signal is applied to the cell which can switch the polarization of the emerging beam through 90 degrees. The beam is passed through a calcite lens which has different refractive indices for the two polarizations. Therefore, two different degrees of convergence of the beam can be obtained.

By using up to three such cells, eight different focus conditions are sufficient to give smooth change of focus with distance. By correct design of this focussing system, the increased convergence of the beam needed to focus on near objects can be linked with a decrease in pupil size to give a better overall result.

CONCLUSIONS

An advanced, high-resolution wide-angle visual system for military flight simulation has been described. The basic feasibility has been established but the practical realization of the system remains to be proven. Satisfactory conclusion of this work will provide a substantial advance in visual simulation.

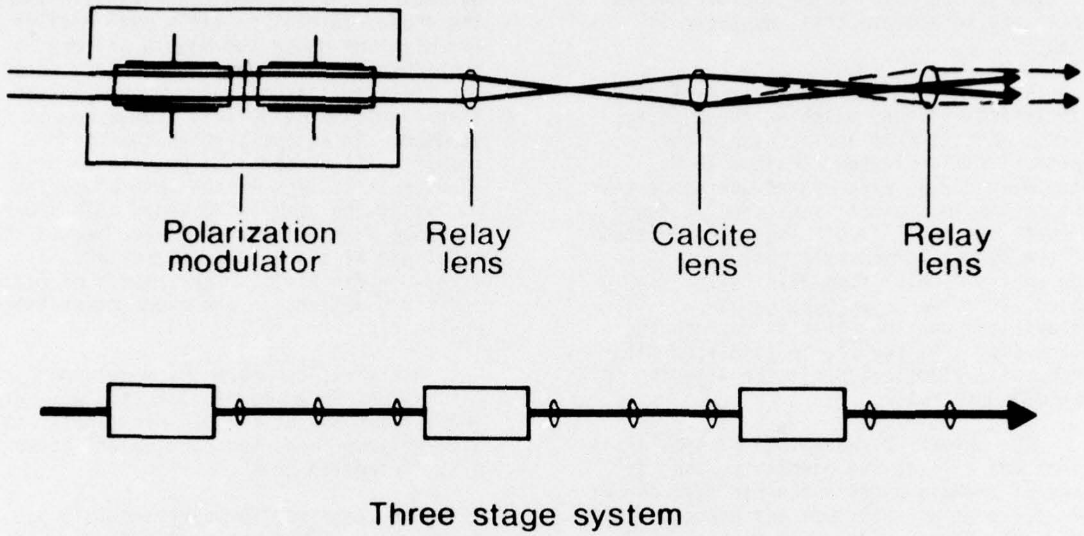

Figure 5. Electrooptic Method of Focussing

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A DATA BASE GENERATION SYSTEM FOR DIGITAL IMAGE GENERATION

BY
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INTRODUCTION

In the last ten years, we have witnessed a fortyfold increase in the edge processing capability of real-time digital image generation (DIG) systems. While it would appear unlikely that the next decade will produce another fortyfold increase in capacity, one thing, at least, seems clear. Like some insatiable science fiction monster, today's DIG system is devouring data bases at a prodigious rate that promises to be ever-increasing. To satisfy this gargantuan demand, as well as the desire of users for more detailed and realistic simulation, greater emphasis will have to be placed on the data base generation process. Indeed, we have already seen the beginnings of this trend in recent procurement specifications such as that for the DIG for the FB-111 simulator, (1) which not only specifies a total data base storage capacity several times the size of the deliverable data base, but also requires the delivery of a data base generation facility, thus hinting at the Government's intent to fill up this spare storage capacity after delivery. In recognition of the substantial effort required to generate visual simulation data bases, there is even a quantitative specification of data base generation speed.

A comparable situation exists in the radar simulation field, and it is interesting to observe what has transpired there. The need for greater modification capability and higher resolution has led to the adoption of the digital radar land mass simulation (DRLMS) system over the earlier analog (transparency) system far faster than has been the case with visual simulation. Data base generation for DRLMS started with automated scanning and digitization of existing analog RLMS transparencies, and is now tending to standardize on data compiled by the Defense Mapping Agency Aerospace Center (DMAAC) in St. Louis, Mo. At DMAAC, there has been a substantial investment in equipment and personnel to facilitate the encoding of photographic and topographic data, primarily for radar simulation purposes.

The applicability of this data for forward-looking infrared (FLIR) and low-light-level television (LLLTV) sensor simulation has apparently been recognized, (2) and from there it is a natural step to extend its use to visual simulation. Not only would this reduce the cost of visual data base generation, but it would also result in correlated imagery spanning a wide array of sensing equipment. This paper describes a system which has been developed to utilize DMAAC source data for DIG visual simulation; it also describes the laboratory real-time DIG system used for validation of the results.

LABORATORY DIG SYSTEM

Concurrent with the development of the data base generation system was the development of a real-time laboratory DIG system, which served as the test-bed and demonstration vehicle for the data base generation development. The laboratory DIG hardware will be briefly described to illuminate the environment in which the data base must operate, although continuing development has since resulted in more powerful capabilities.

Figure 1 is a block diagram of the laboratory DIG system. Operation of the system is controlled by a Datacraft (now Harris) 6024/5 general-purpose computer. This same computer was the central controller for the data base generation system. The computer communicates directly with the frame calculator, whose function is to translate, rotate, clip, and project data base face boundaries onto the computed image plane, and store the results in the double-buffered edge list. The frame calculator operates on object descriptions extracted from the active data base (ADB) store, a 16K x 48-bit core memory loaded through an alternate data path by the general-purpose computer.

Edge list contents for an entire frame's computation are processed on a line-by-line basis by the scanline computer to produce a sequence of visible scanline segments, which are converted to video information

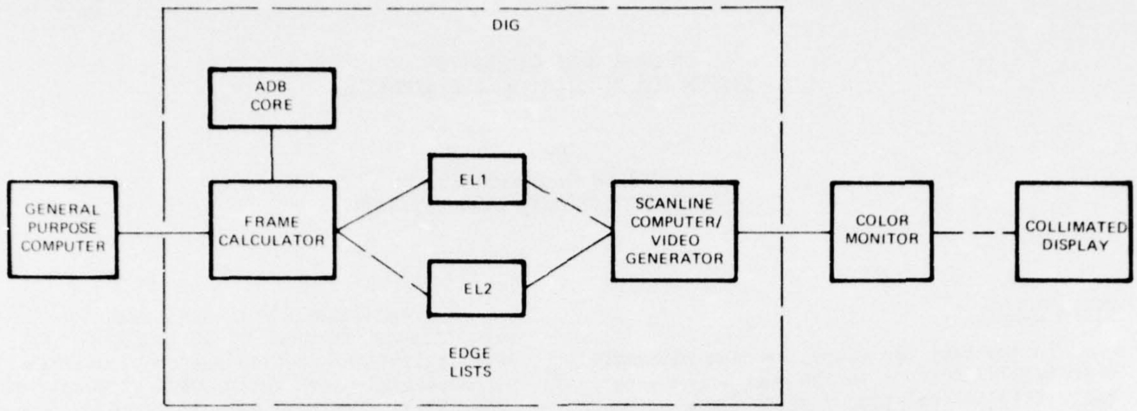

Figure 1. Laboratory Dig System

by the video generator. This is displayed on a high-resolution color monitor viewed through a collimating mirror-beamsplitter display system.

As far as features and capabilities are concerned, the system handles about 5,600 face boundaries in real-time (30 frames per second) and generates 1,000 scan lines, each with 1,000 resolution elements. Up to 256 edge intersections can be accommodated per scan line, and this level can be sustained on every scan line. Smooth-shading is incorporated to provide a rounded appearance to curved surfaces. At any one time, up to 64 distinct colors may be displayed; each color is specified by 18 bits, 6 each in the red, green, and blue primaries, to form a potential color space of more than 262,000 possible hues. Horizontal and vertical edge smoothing techniques have been included to minimize quantization effects.

The system uses a priority list technique for resolving visibility contentions between objects which overlap when projected onto the image plane. This approach constrains objects to be convex, so as to preclude the overlapping of faces of the same priority. Up to 256 priorities may be specified. Object priorities are typically assigned in real-time by the general-purpose computer, using a separating plane approach.[3,4] Types of objects which may be specified include two-dimensional objects (parallel to the ground plane), three-dimensional objects (solid or oblique to the ground plane), point lights, strings of point lights, and lines. Lights can be specified to be either 1 scanline by 1 resolution element or 2 scanlines by 2 resolution elements in extent. Lines can be either 1 or 2 elements wide. Objects which are not lines or lights may either have their face intensities computed dynamically, as a function of sun position and face orientation, or be specified to be constant. This latter capability has been used to minimize real-time computation requirements and to provide for unusual sensor characteristics, such as are found in FLIR or LLLTV simulation. Owing to a particular choice of clipping algorithm, all non-light, non-line faces are constrained to be convex (this constraint has been removed in later designs).

DATA BASE GENERATION SYSTEM HARDWARE

The physical emodiment of the data base generation system (DBGS) is depicted in Figure 2. The central element is the central processing unit (CPU), which is the same one used for the real-time DIG system. It includes 48K 24-bit words of 1-microsecond core memory. The DIG and display are also included as part of the DBGS hardware, since debugging and final proofing are an integral and necessary part of the data base generation process. In addition, in conjunction with the joystick and controls, it provides a medium for interactive data base modification, as described in a later section.

Peripheral devices connected to the CPU, aside from the normal teletypewriter, card reader, and line printer, are a 28-megabyte (9 million words) moving-head disk, used for data base and program storage, and a 9-track magnetic tape system, used for backing up the disk and providing additional flexibility to interchange data bases. It is also the input device for the DMAAC data base.

The display terminal is a Tektronix Model 4010-1, consisting of a storage screen display and alphanumeric keyboard, which includes hardware vector and character generation. Graphic input is also permitted

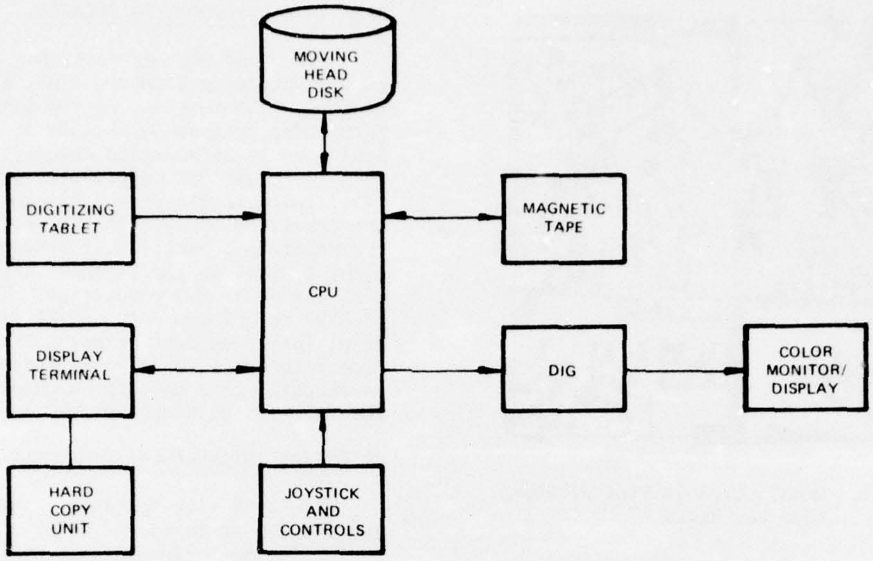

Figure 2. Data Base Generation System Hardware

through thumbwheel control of a crosshair cursor. This device serves as the primary unit for graphic interaction and for geometry verification prior to real-time display with the DIG. Connected to the display terminal is a Tektronix Model 4610 hard copy unit, which produces facsimile copies of any information on the display screen. This is used to provide automatic documentation of the data base.

The digitizing tablet is a Science Accessories Corporation Model GP-2 Graf/Pen, with 12-bit resolution over a 36- by 36-inch active area. This is used as the primary input device for the modification of the data base, and for the entry of new features or geometry not contained in the DMAAC source data.

THE DMAAC DATA BASE

The DMAAC digital data base (DDB) was conceived to satisfy the requirements for digital radar land mass simulation (DRLMS), initially on Project 1183. [5,6] At the time of this work, the DDB consisted of two distinct portions: an elevation file, which defined predominant ground contours by means of elevation values at evenly spaced (in latitude and longitude) grid points, and a cultural file, which consisted of orthographic outlines of cultural features, along with some natural features such as lakes and rivers. It is the latter file on which the present work is based, there having already been some work done on processing grid point information to produce a DIG-compatible data base. [7,8]

The cultural file is organized into manuscripts, rectangular (in latitude/longitude) areas at a given data resolution level. Of these there are three, the finest being 50-foot resolution. Within each manuscript, each feature is assigned a unique feature analysis code (FAC) number, and is encoded geometrically by a directed sequence of vertices, defined in geocentric coordinates, and a predominant height, which is equal to zero for ground level (2-D) features. Additional descriptive information carried along with the feature includes the feature identification (FID), a number which determines the feature's general category (tennis court, commercial building, water tower, etc.), surface material type, percent of roof cover, and percent of tree cover.

It was considered important that the trial DIG data base consist of as much detail as possible. At the time of this work, only the 57,000-square-mile Project 1183 data base was available; the most detailed manuscript therein (Level 3B) consisted of 1 square mile of downtown Las Vegas, and contained about 4,300 vertices. A plot of the manuscript is shown in Figure 3. The decision to use this manuscript was met with grudging acceptance by the data base modeler, who reluctantly volunteered to conduct on-site data gathering activities to supplement the DMAAC DDB.

DATA BASE GENERATION SYSTEM

The data base generation process, as well as the software modules required to implement

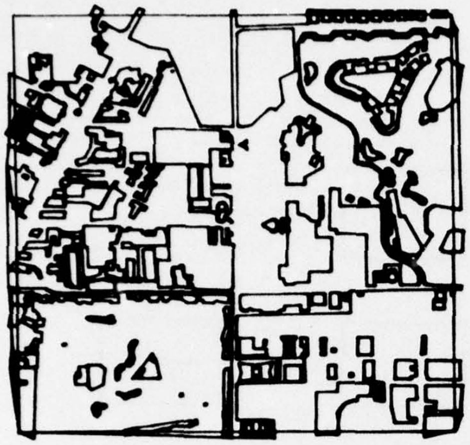

Figure 3. DMAAC Level 3B Plot of Downtown Las Vegas

the process, is illustrated in Figure 4. The elements of this system are discussed below, and consist of the Data Tape Reformatting Program, the Data Base Enhancement Program, the Data Base Compiler, the Perspective Line Drawing Routine, the Demo Program, and ancillary programs.

DATA TAPE REFORMMATING PROGRAM

The DMAAC DDB was furnished on a magnetic tape prepared on a UNIVAC 1108, a 36-bit machine. The function of the Data Tape Reformatting Program (DTRP) was to search the tape for the appropriate manuscript, convert all items for compatibility with the 24-bit word length of the Datacraft CPU, and transform the geocentric vertex coordinates to a rectilinear system in a plane tangent to the earth at the southwest corner of the manuscript. The output of DTRP is written onto a disk file (DTRP file) for convenient access by the Data Tape Interpretation Program (DTIP). DTRP is executed only once for a given manuscript, and involves no human interaction.

DATA TAPE INTERPRETATION PROGRAM

The DTRP file contains a combination of 2-D and 3-D features, of which the 3-D features must be "extruded" out of the ground plane to the extent of their predominant height. As in the case of the Level 3B manuscript, feature outlines which should ideally be smoothly curved (e.g., the Landmark Tower) are ragged and uneven, and contain unnecessary vertices. In addition, the manuscript contains many more vertices than the

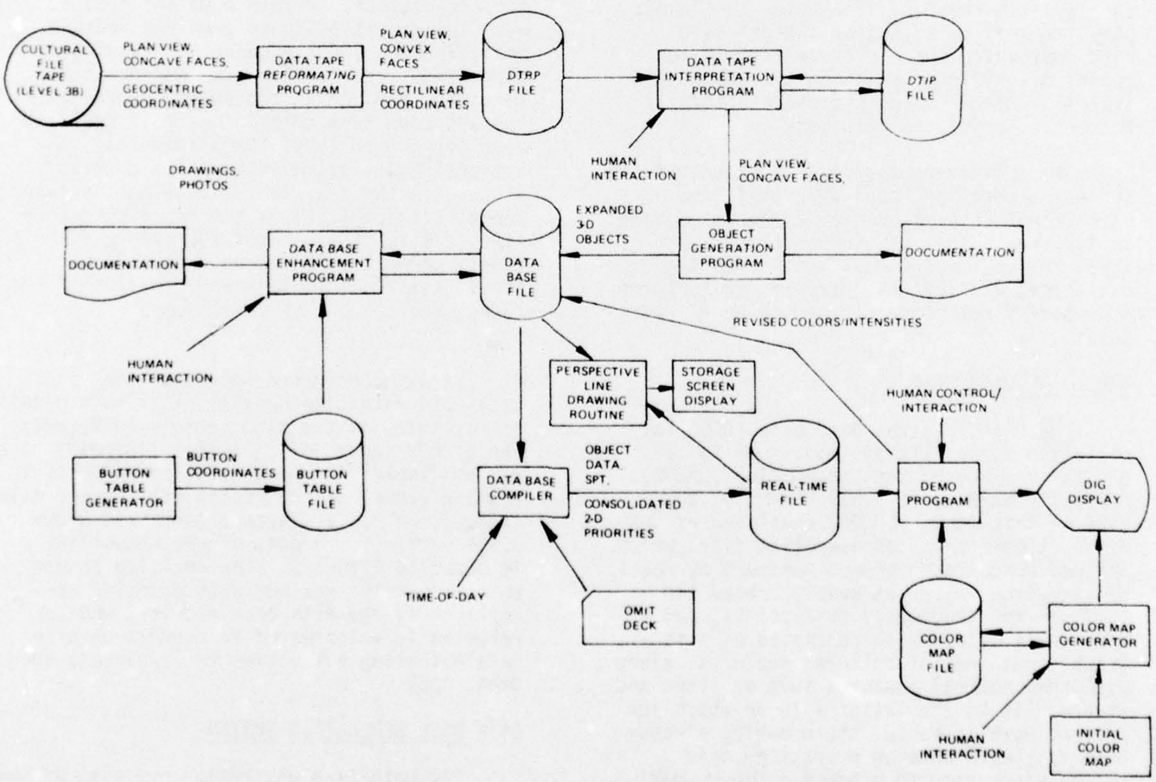

Figure 4. Data Base Generation Process

DIG system is capable of handling: of the 4,300 vertices in the Level 3B manuscript, approximately 2,400 are contained in the 145 3-D features. When these features are extruded from the ground, an additional 9,600 face boundaries will be created, for a total, including 2-D, of 13,900 face boundaries, without even considering those that are added to force convexity. Consequently, a considerable number of vertices must be eliminated in order to remain within the DIG processing capacity, and the remaining vertices must be chosen for efficient and accurate portrayal of feature outlines, as well as for subjectively important qualities such as symmetry and regularity. This process requires a high degree of human involvement, which is facilitated by the Data Tape Interpretation Program (DTIP) in conjunction with the storage screen display terminal.

Using DTIP, the data base modeler works on one feature at a time, first selecting it, either by referencing its FAC number or by positioning the graphic cursor anywhere within the feature boundary, and then modifying its geometry as required, using an orthographic plot of the feature or the entire manuscript. This modification may be done by deleting or moving existing vertices, or by adding new ones. An alternate mode allows complete respecification of a feature through the sequential placement of its defining vertices. In all cases, vertices are referenced or placed by positioning the graphic cursor and depressing the "space" bar on the keyboard.

On the 5- by 7-inch display terminal screen, a 4½-inch square area on the left is reserved for the graphic plots. The right-hand scale of the screen is reserved for the display of the menu, or listing of allowable actions at each step of the modeling process. Each action is identified with a digit (0-9) and is selected by activating the appropriate digit key on the keyboard. Additional display fields identify the name of the file being plotted from, and the scale of the plot. The use of the former field arises from the identical formats of the DTRP and DTIP (output) files; consequently, either file may be used as the starting point for modifying a feature description. The need for the latter field is due to the capability at various steps to redefine the extent of the plot, either by zooming in or out by a factor of two, or by arbitrarily defining new extents with the graphic cursor.

When the modeler is satisfied with the appearance of a feature (at least in an orthographic view), he may declare it to be "complete." At this point, the feature boundary is not necessarily convex. Since this is harmful from two standpoints (nonconvex faces and nonconvex objects are not allowed), steps must be taken to insure orthographic convexity. This is done automatically in DTIP by adding internal edges connecting selected vertices, so that the feature is divided into a set of convex faces. The result is plotted on the display screen to allow the modeler to determine whether the "convexitization" is optimum (i.e., minimum number of internal edges); he may wish to delete or move vertices so that fewer faces are generated, or he may wish to define the internal edges himself, a capability which has been provided because the present convexitization algorithm is not optimum.

When all is complete and satisfactory, the modeler then "saves" the feature. This passes the feature description to the Object Generation Program, after first verifying that the feature, if 3-D, does not overlap any existing 3-D features in the DTIP file. Were this to be so, overlapping objects would be generated; these are not allowable with the priority list technique.

OBJECT GENERATION PROGRAM

The Object Generation Program (OGP) is actually a subroutine called by the DTIP mainline, and after execution it returns to DTIP to allow work on additional features. The function of OGP is to convert the feature descriptions from the DTRP/DTIP format (which takes advantage of the orthographic nature of the vertex information to reduce storage) to a true 3-D data base file (DBF) format, after first expanding 3-D features by adding "walls" to the "roofs."

The DBF format (see Figure 5) is a hierarchical list structure, consisting of feature, object, face, vertex reference, vertex coordinate, and vertex normal beads (the latter only for smooth-shaded objects); each bead, or cell, consists of a contiguous (in memory) sequence of words which define the requisite information for that level of the structure, as well as pointers to the next bead at the same level and the first bead at the next lower level. This type of format lends itself to convenient addition, deletion, or revision of information.

In addition to the mechanical task of converting file formats, OGP also calls a series of routines which provide automatic hardcopy documentation of the feature, including objects, faces, and vertices. This documentation, is extremely valuable during later debugging.

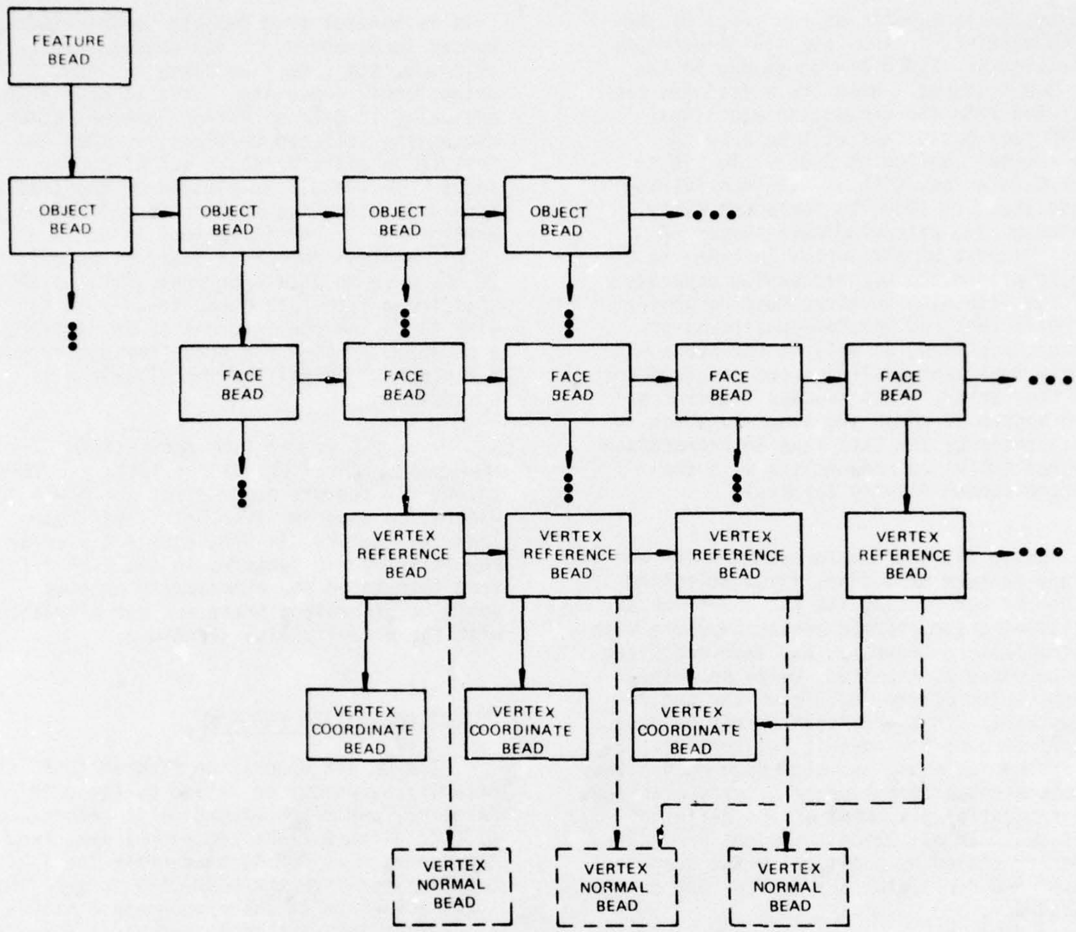

Figure 5. DBF Data Structure

DATA BASE ENHANCEMENT PROGRAM

Not all significant features can be extracted from the DMAAC DDB, and some of those that can are not well represented by simply expanding them in three dimensions. For example, the Las Vegas Convention Center dome is extremely recognizable in the real world, but not in the DMAAC data (Figure 6); the Landmark Tower, while it is represented as a separate feature in the DDB (Figure 7), would not, when mechanically expanded, allow the accurate portrayal of the actual structure. In cases like this, source material other than the DMAAC DDB must be used. The Data Base Enhancement Program (DBEP) allows the entry of this information into the data base, and is also the principal tool for the modification of the data base.

DBEP is controlled exclusively from the digitizing tablet, using predefined areas of the digitizing surface as "buttons" which

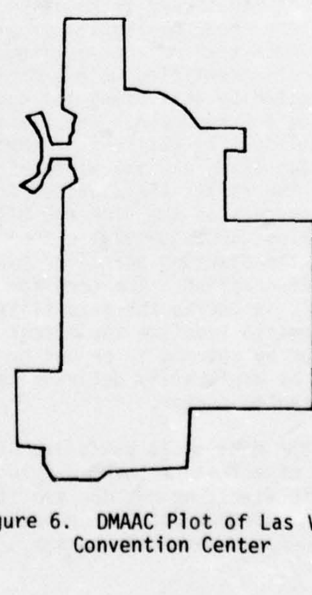

Figure 6. DMAAC Plot of Las Vegas Convention Center

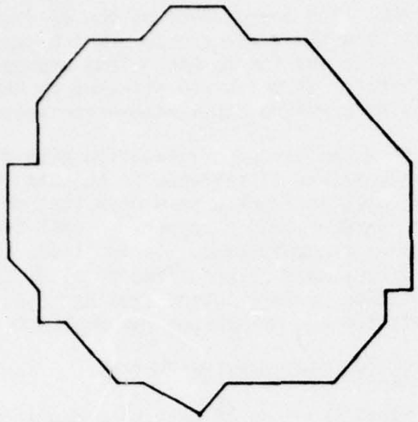

Figure 7. DMAAC Plot of Landmark Tower

the data base modeler may activate at the appropriate times. In addition, the tablet is also used as a pure graphic input device, allowing entry of specially formatted drawings. For 2-D features, these drawings depict a plan view of the faces to be entered. For 3-D features, both plan and side views are represented on the drawing, one above the other, as shown in Figure 8. To digitize a face from this drawing, corresponding pairs of vertices from the two views are entered in counterclockwise order around the face. A perspective view of the solid figure obtained from the drawing in Figure 6

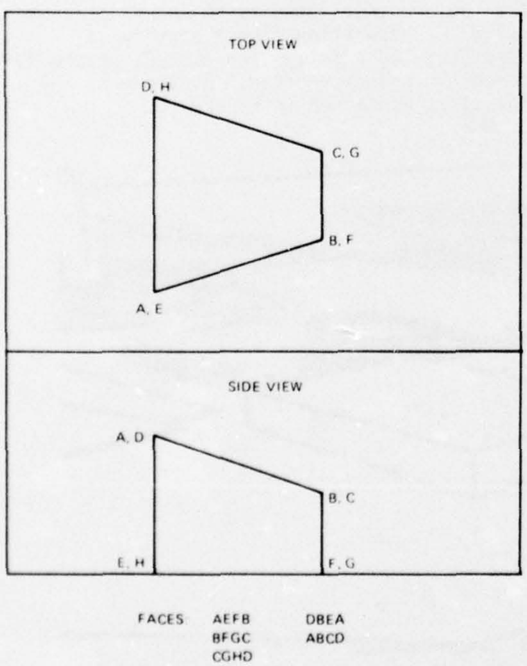

Figure 8. Three Dimensional Data Entry

is shown in Figure 9. While less elegant than some other approaches for 3-D data entry,[9] this scheme was nonetheless easy to program and proved quite workable in practice.

Aside from the ability to enter new features, DBEP also provides feature modification and manipulation capabilities. For example, existing faces, objects, or features may be translated, rotated, or both; face colors may be selected; vertex normal vectors may be automatically computed as an average of face normals, or may be specified numerically; duplicate copies or mirror images of existing features or objects may be created; and existing features, objects, faces, or vertices may be deleted from the data base. Extensive error checking is conducted at all steps to insure object and face convexity and face planarity, among other conditions. At any time partial documentation may be requested for an intermediate check on data validity, and automatic documentation is generated upon saving a feature in the DBF. The documentation routines used are the same as those called by OGP, and also provide a check for linear separability of objects within the feature. In all, DBEP provides a powerful tool for data base generation and modification.

DATA BASE COMPILER

Prior to being loaded into the DIG ADB core, the data base must be converted from the easily updatable list format in the DBF to the highly compressed format required by the

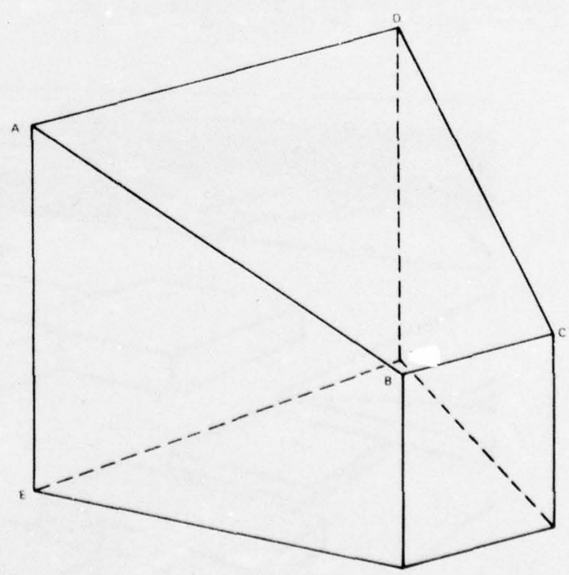

Figure 9. Perspective View of 3-D Solid

DIG processing hardware, a function performed by the Data Base Comiler (DBC). In the process, default face colors and intensities must be assigned for those faces extracted directly from the DMAAC DDB, which contains no color information. At present, this assignment is based only on FID number; where the modeler wishes this assignment to be overridden, he must manually enter a color/intensity combination with DBEP. Intensities for other sensors (FLIR, LLLTV) can also be derived during this stage of the processing.

In addition to the data conversion, the DBC performs two other important functions: 2-D priority consolidation, and separating plane generation. Since 2-D faces are all in the ground plane, they can all be assigned the same priority number, provided they do not overlap, without any deleterious effects appearing in the display. However, some 2-D faces purposely overlap others to minimize the number of face boundaries required. 2-D consolidation seeks to conserve priorities by collecting 2-D faces into the minimum number of priority classes, where all members of a class are assigned the same priority number. In the Las Vegas data base, 35 2-D features were reduced to only four priority classes, thus allowing a greater number of 3-D objects.

Whereas the priorities of 2-D objects can be assigned during the data base compilation, those of 3-D objects depend on their position and arrangement relative to the observer. Consequently, computation of these must be deferred to real-time. The concept of separating planes allows the convenient precalculation of object priorities using the modest facilities of the general-purpose computer. The computation of the separating planes, and the tree structure which defines their relationships to each other and to the 3-D objects, is performed off-line by the DBC using a refined trial-and-error technique.

To allow for experimentation with different versions of features or objects, the DBC accepts as input a card deck that defines which features and/or objects to omit from the current compilation. In addition, the time of day must be specified to allow the computation of face intensities based on face orientation and calculated sun position.

PERSPECTIVE LINE-DRAWING ROUTINE

Final proofing of data base geometry, prior to actual display with the DIG, is done through the generation of perspective line drawings, with hidden-line removal based on the separating plane/priority list approach. In order to allow convenient user specification of the viewpoint position and orientation for generating the line drawing, the Perspective Line-Drawing Routine first creates a hard-copy orthographic map of the data base on the storage screen display, using just the objects obtained from the last previous data base compilation. The user then tapes this map to the digitizing tablet, locates the map by digitizing two corners, and then digitizes the positions of both the viewpoint and the point being viewed, first in X-Y directly on the map, and then in Z using a scale along the side of the map. The routine then computes object priorities using the separating planes previously compiled, and displays the objects on the 4010 screen in priority order. A sample of the output is contained in Figure 10.

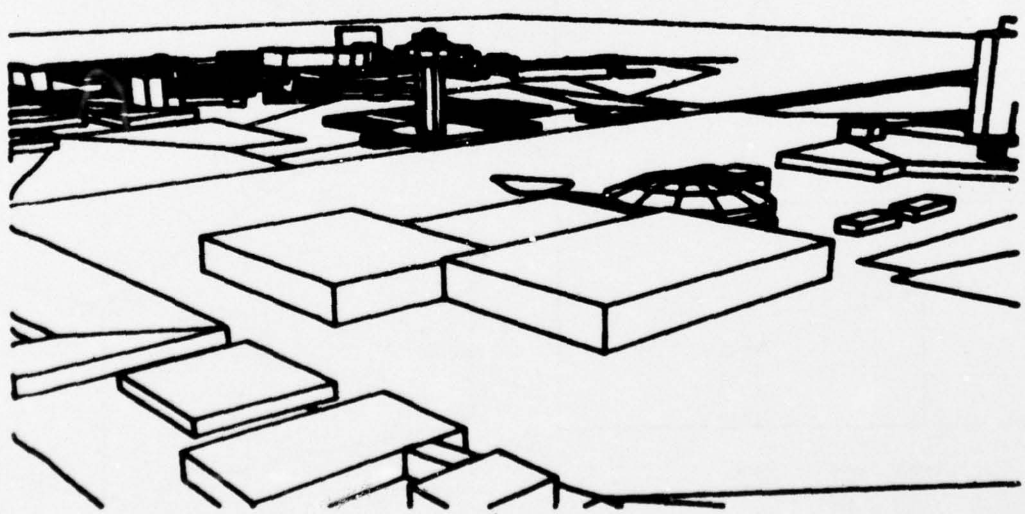

Figure 10. Perspective Line Drawing of Las Vegas Data Base

DEMO PROGRAM

The proof of the process is actually viewing the data base in real time on the color display, under the control of the Demo Program. The Demo Program performs three primary functions:

1) Aircraft emulation - using joystick and switch inputs, observer position and attitude are calculated according to simplified aerodynamics;

2) Priority calculation - priorities of 3-D objects are computed by traversing the separating plane tree;

3) DIG communication - commands and data are transferred to the DIG processing hardware using standard communication subroutines.

Aside from the viewing capabilities provided by the above functions, the Demo Program also provides a powerful data base debug and modification capability. By enabling the Color Modification portion of the program with a switch at the control console, a user can cause a small square cursor to be generated in the picture. This cursor is responsive to joystick motion, and can be positioned over any face or object. When a button on the joystick handle is depressed, the numbers of the feature, object, and face overlaid by the cursor are printed on the teletypewriter. Then, by means of slew switches on the control console, the user may dynamically change the color and/or intensity of the object/face while observing the effects on the display. Future enhancements of this capability may include the ability to adjust vertex normals for smooth-shaded objects.

ANCILLARY PROGRAMS

Two ancillary, but important, programs have not yet been discussed: the Button Table Generator and the Color Map Generator. The Button Table Generator allows the definition, using the digitizing tablet, of the coordinates of buttons used by DBEP. In addition, it allows the checking and modification of button locations, and the addition of new buttons. The output of the Button Table Generator is stored on a disk file accessible to DBEP.

The Color Map Generator allows the specification of the 64 possible colors which comprise the permissible color space at any one time. This specification takes the form of a six-bit value for each of the red, green, and blue (R, G, B) components of the desired color. The specifications for all 64 colors are contained in a random-access semiconductor memory in the video generator, called the color table or color map. The color map can be thought of as a catalog of paint chips, from which the data base modeler can select the colors of faces and objects. Each chip has a number, from 0 to 63, which is the address of the color map entry for that chip; this number is what is carried along in the data base to represent color, and during the video generation process, a table lookup is used to transform from this number to the actual CRT drive voltages. The color table is loaded during the initialization phase of the Demo Program from the color map in the Color Map Disk File, which is generated in turn by the Color Map Generator.

It had initially been thought that the color map entries would be empirically determined using the actual display. However, a superior, purely analytical approach was developed which allowed the determination of color map entries directly from the hue, value, and chroma information supplied with each color chip in the Munsell Book of Color, [10] which was used as the basis for color selection. This determination took account both of the color CRT phosphor capabilities and the transfer function of the D/A converters and gamma correction circuitry in the video generator. The results achieved with this approach were outstanding, and no empirical correction was required to match the original Munsell colors within human discernibility limits.

RESULTS

As indicated, the DBGS was used on the DMAAC Level 3B manuscript of downtown Las Vegas. Using DTIP, the original 4,300 vertices were reduced to 1,783, the result of eliminating about 60 features, retaining 50 in their original form, and using DTIP to "outline" another 50. The orthographic data base, after all work with DTIP, and including edges added for convexity, is shown in Figure 11.

After this step, drawings were prepared and digitized for another 13 features, including the Convention Center dome, Circus Hotel, Landmark Tower, and Hilton Hotel. The resulting 3-D data base, consisting of about 5,300 face boundaries, is shown in Figure 12, which is reproduced from a photograph taken from the DIG monitor. Additional photos of this data base are contained in Reference 11.

The versatility of the DBGS, particularly DBEP, is illustrated in Figures 13-16, which are DIG photographs of data bases for the space shuttle orbiter, a terrain-following range, and day and night versions of the San Jose Municipal Airport. These data bases started with drawings, so DTRP and DTIP were not used.

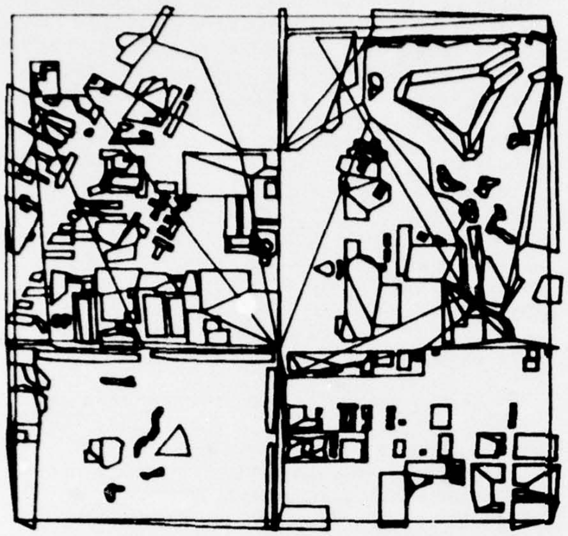

Figure 11. Las Vegas After Modification with DTIP

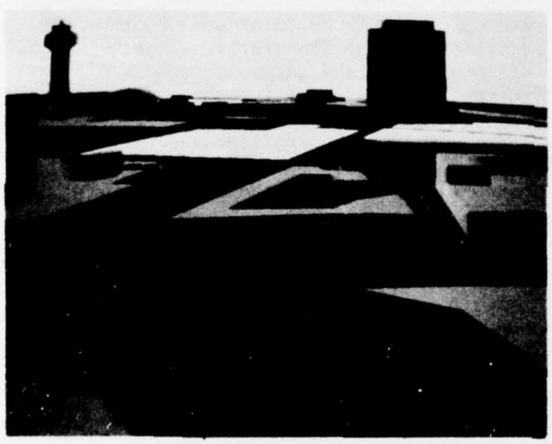

Figure 12. Las Vegas Data Base

FUTURE DEVELOPMENT

Many shortcuts were taken in the design of DTRP and DTIP to take advantage of known characteristics of the Level 3B manuscript, including geographic location and maximum number of vertices. The design of these modules should be generalized to allow handling of arbitary manuscripts. This will include matching of features from adjoining manuscripts, and from manuscripts at different levels of description. Some automation can be incorporated into the program to, for example, eliminate redundant collinear (or nearly so) vertices based on a user-supplied tolerance. In addition, data may have to be organized differently to satisfy the requirements of dynamic data base retrieval programs, which will probably be inevitable in any nontrivial simulation application. These changes will of course propagate through the other programs of the DBGS, principally the DBC.

CONCLUSION

The data base generation system described herein demonstrates the feasibility of semi-automated methods for the production of cultural DIG data bases for visual simulation. This approach depends on a pre-existing source of digitized data covering a large geographic area, and is made economical through increased automation of decisions and inclusion of visually significant information (e.g., colors, intensities, textures) in the source data. While human intervention in the data base generation process will never be totally eliminated, it can be reduced to those areas in which human facilities are superior to those of machines: pattern recognition, perceptual judgement, and determination of importance to training.

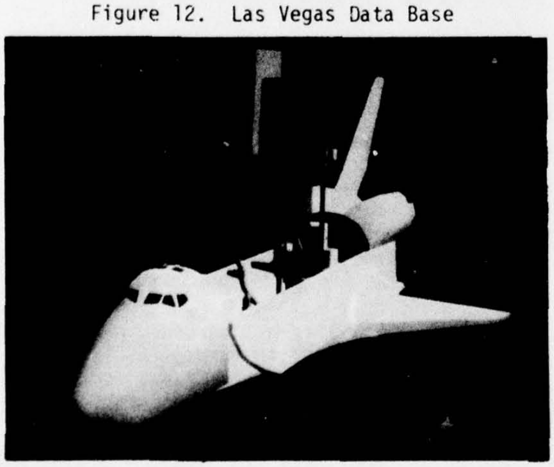

Figure 13. Space Shuttle Orbiter

Figure 14. Rolling/Mountainous Terrain

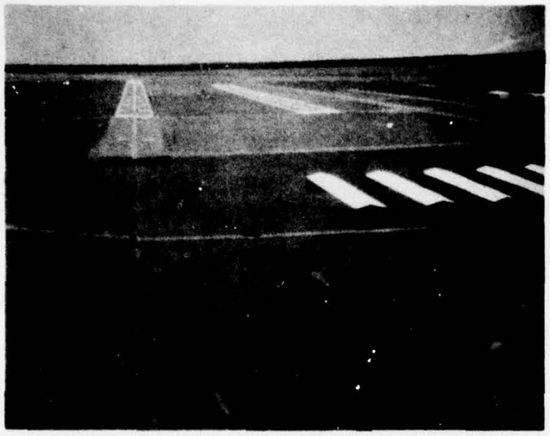

Figure 15. San Jose Municipal Airport (Day Version)

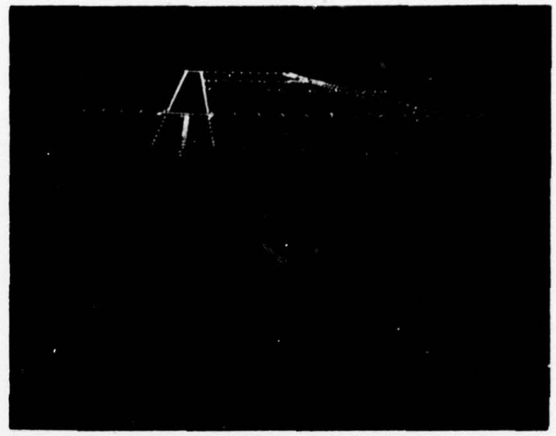

Figure 16. San Jose Municipal Airport (Night Version)

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A NEW VISUAL SIMULATION TECHNIQUE FOR PILOT TRAINING

CARL J. VORST
McDonnell Douglas Electronics Company

INTRODUCTION

Visual simulation has become a major factor in replacing aircraft hours with simulator hours for pilot training. Rapid increase in visual use, made possible by computer generated imagery (CGI) technology, is in turn a major factor in increased simulator use. Generally replacing television model and film approaches, CGI has demonstrated training flexibility and low cost when properly applied. This paper presents application of a new CGI technology particularly suited to the problem of pilot training; that technology being the heart of the VITAL system developed by McDonnell Douglas Electronics Company.

A general CGI characteristic is that equipment complexity is directly related to instantaneous scene content. Of the two general CGI categories, raster and calligraphic (stroke written) scan, both require similar size data base storage and processing capability. An important difference is that raster scan requires a significant amount of parallel processing while calligraphic processing is serial. This translates to the potential for considerable hardware savings with calligraphic use.

Consideration of visual requirements demonstrates that overall instantaneous scene complexity is roughly constant in a pilot training application. Figure 1 is an example which illustrates this by comparing two steps in a landing sequence. At six miles from touchdown (Figure 1a) a large number of light points are in view but very few solid surfaces may be seen. As the approach continues, light points pass out of view, while visible surfaces grow in size and number. At runway threshold (Figure 1b), only a few light points are in view while numerous surfaces of significant size are present.

Figure 1a. 6 Miles from Threshold

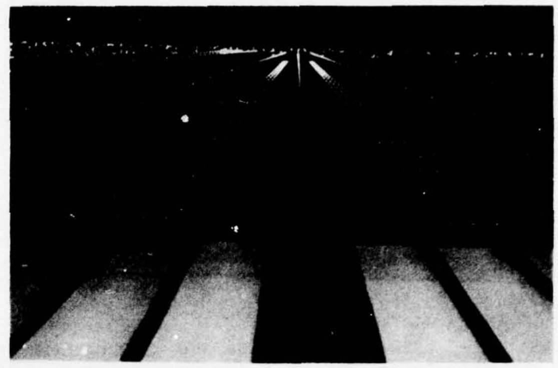


Figure 1b. R. W. Threshold

The sequential nature of calligraphic techniques fits hand-in-hand with such scene requirements in that writing time may split between precision point and surface display as required by instantaneous scene content. While calligraphic light point display has for some time been successfully performed with a jump-settle-unblank sequence, efficient generation of smoothly textured surfaces has been the subject of much research.

VITAL surface generation (Figure 2) implements a calligraphic technique uniquely developed for the VITAL application, which eliminates earlier problems. The surfacing device, descriptively named "Raster Blaster," is pipelined between a general-purpose computer and a high-speed color graphics display unit. The Blaster is designed to generate precision points and surfaces of uniform texture with minimum computer intervention. It contains the complete functions beam steering, blanking, surface shading, along with the control of color, intensity, and focus. A detailed description of the device and its design follows.

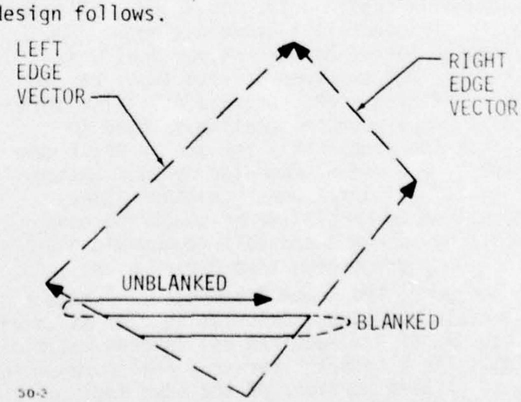


Figure 2. Vital Shape Generation

VITAL System Concepts

The Virtual Image Takeoff and Landing (VITAL) system was formulated as a solution to a particular visual simulation problem. That problem was one of twilight and night takeoff and landing under a variety of visibility conditions. Several unique design concepts, particularly in the area of surface generation electronics, were used to satisfy the requirements posed by this application.

The system (Figure 3) is partitioned into four elements: 1) system inputs, 2) image generation equipment, 3) picture controller (Raster Blaster), and 4) display electronics. This third element, the Raster Blaster, is the key to system performance. Its function is twofold; first, to generate control signals for display of points, and second, to generate control signals for display of surfaces. Because of its special advantages the surface generation concept will be discussed in detail.

A surface is defined in terms of its outline, represented by a segmented right-edge vector and a segmented left-edge vector. The beam is moved in alternate directions at a constant velocity and with a fixed separation between horizontal lines within the surface bounds. Constant beam velocity and separation are critical to achieving uniform intensity over the entire enclosed area. Efficient use of the deflection system is made by writing in both directions rather than using a blanked retrace. To aid in maintaining constant beam velocity and line separation, the beam is blanked outside the shape bounds and time allowed for beam settling.

In the Blaster, surface reconstruction is performed by the X and Y computers, and by the sweep generator. The X computer incrementally generates a representation of the left and right edges of a surface by adding a ΔX to the current X value each time the beam is incremented by one raster line, ΔY. Storage is provided for the several ΔX's required to generate a segmented edge. The Y computer generates current vertical beam position and compares it with the Y coordinates of edge vector breakpoints. The breakpoint comparison information is used to select the proper ΔX's for use by the X computer. The sweep generator defines instantaneous horizontal beam position. Sweep direction is controlled by comparing beam position to right and left-edge position. To reduce processing time during beam turnaround, the X and Y computers operate as separate pipelines, calculating data ahead of the time of its required use in beam positioning. The X computer serves a dual purpose in that it uses portions of the edge logic as a lightpoint pipeline.

Much of the geometric appearance of CGI scenes is removed by applying shading to surfaces. Figure 4 illustrates the effect continuous shading has on scene quality. With shading, a realistic tapered horizon glow is provided, fading smoothly as angle above the horizon increases. Intensity taper on the runway surface provides a depth cue and may be used to represent the effect of landing lights on surface visibility.

Intensity taper is under full control of software. The Z computer uses software supplied shading coefficients in combination with horizontal and vertical deflection signals to produce an interpolation of intensity simultaneously in X and Y. To represent a background illumination in conjunction with intensity taper, as would be found in a twilight landing scene, the Z computer has provisions to clamp intensity to a program controlled minimum level.

Focus control logic operates on the CRT focus amplifier to produce light points of a controlled size regardless of color. It may also be used for commanding defocus of points or shapes as required by special applications. It is possible to expand focus control to include a focus taper, much like the intensity taper.

Design Considerations

While simple in concept, numerous considerations entered into the final design. Design characteristics of special importance were first defined. These characteristics were matched to potential implementations and then evaluated through methodical testing. Quite often this meant scrapping a design and starting over.

Design goals of special importance to the VITAL form of point and surface generation were:

for points -

- provide point capability for standard approach and runway patterns along with miscellaneous background lights and landmarks.
- allow settling time that is a function of deflection distance.
- arrange points in strings to reduce average deflection distance.
- pipeline data transfers to minimize effects of I/O data rates.
- provide separate adjustments for color geometry (gain, offset, rotation, brightness).

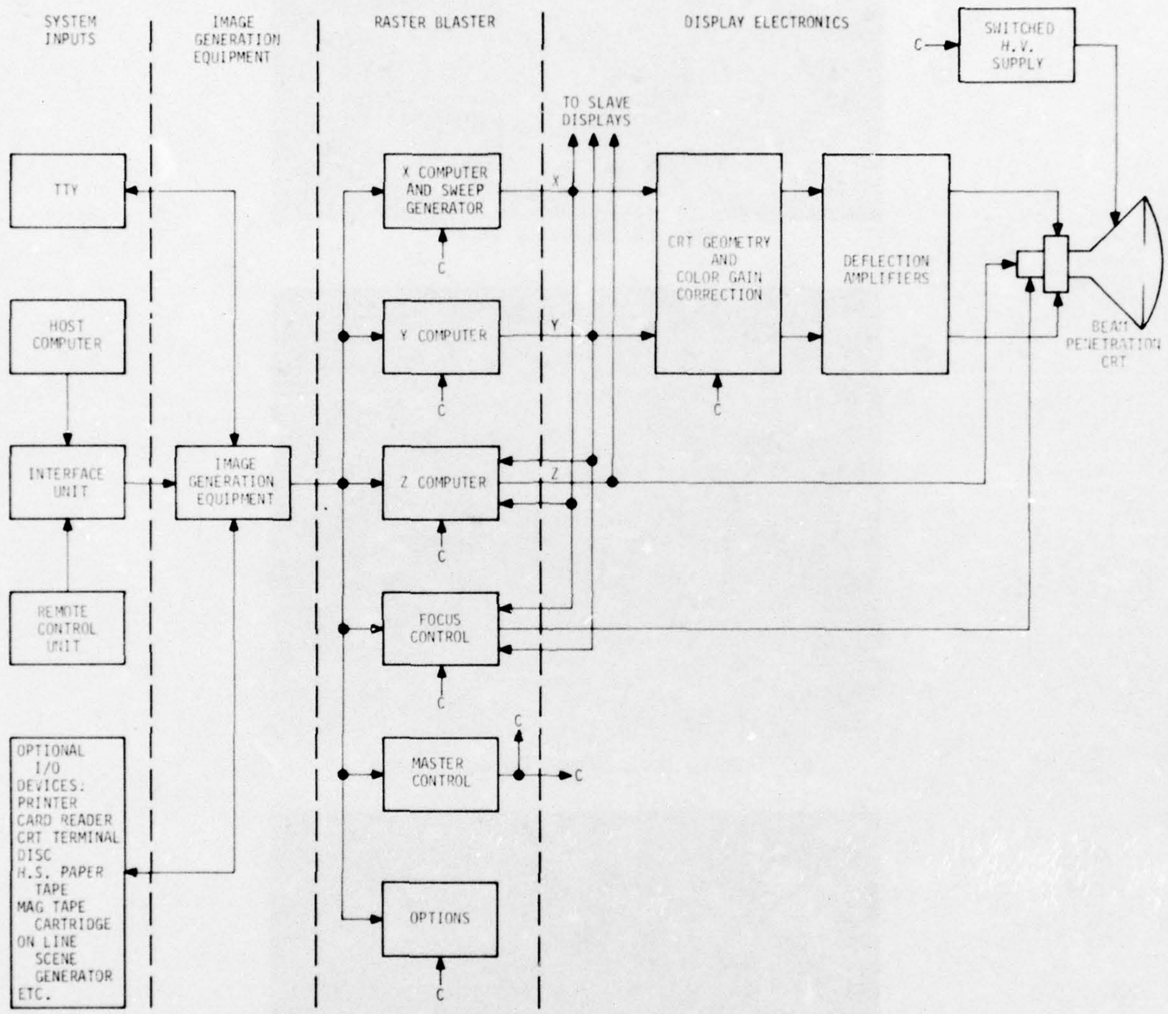
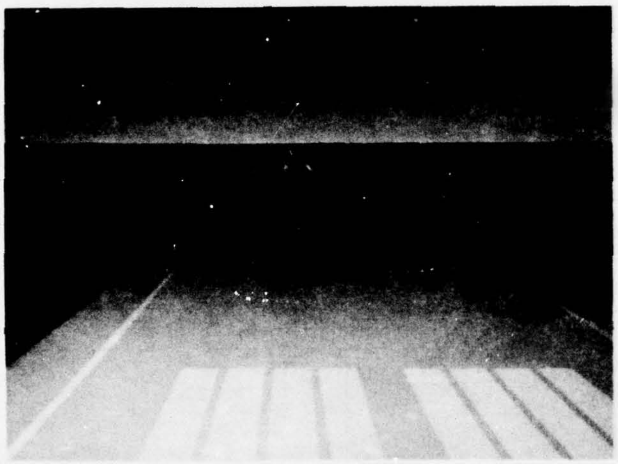


Figure 3. The Vital System

a. No Intensity Taper



b. Tapered Horizon and Runway Intensity

c. Variation of Intensity Taper - Right Outboard Landing Light On

Figure 4. Effects of Intensity Taper

for surfaces -

- achieve writing rate sufficient to present a horizon glow, runway surface with standard markings, and other special elements such as taxiways and key buildings.
- maintain intensity uniformity over a single surface.
- generate a tapered surface intensity (surface shading).
- provide good edge sharpness.
- avoid edge ripple and face flicker.
- maintain a solid appearance.
- correct for differences in transport delays between deflection and intensity channels.

For the most part, design goals for point presentation were met without the need for fanfare. Surface generation, however, provided some interesting design problems. A few of these are summarized in the following paragraphs.

Decreasing line density increases effective surface writing rate. As line density increases, beam defocus is needed to eliminate visibility of individual lines. Defocus must be used with caution, as surface edges tend to lose definition. Experiments showed that when this was applied to small surfaces, they had a definitely defocused appearance which in some cases was actually more annoying than the visibility of individual lines. Reducing line density also increases the detrimental effects of edge ripple and face flicker on small surfaces. This approach can still be used effectively if applied with care to drawing only large surfaces such as horizon, cloud top and runway; using high-line density for small surfaces.

Writing on retrace, while decreasing surface display time, requires precise control of beam position to prevent noise effects. Much of the design effort has gone towards achieving this control. As can be seen from Figure 5, the beam must be moved quickly and smoothly from one raster line to the next. At high deflection rates CRT brightness is highly dependent upon beam dwell time. Any vertical overshoot, when positioning to a new raster line, generates a potential for the beam overwriting an area covered by a previous raster line. Overwriting alters dwell time, subsequently altering brightness, much as increasing film exposure produces a brighter photo. The regular pattern generated is very noticeable. Vertical undershoot has the effect of reducing uniformity of line density. The partial overwriting that occurs at shape edges, produces edge brightening and increases the visibility of individual line pairs. Care must be taken to select a D/A converter and amplifier combination for Y deflection that minimizes conversion glitches, so as not to aggravate the settling problems.

Horizontal deflection linearity is equally critical to picture quality. Variations in horizontal writing rate produce effective changes in dwell time, with resulting intensity variations. In addition, nonlinear deflection induces errors in edge placement. Horizontal deflection anomalies result from amplifier response factors plus some characteristics that are inherent to the sweep generation method. Amplifier considerations are similar to those for vertical deflection. The sweep generation method must be free from turnaround instability and rate variations. Several possible methods of analog sweep generation are illustrated in Figure 6. Digital ramp approaches were avoided because of the high update rates required for low-position granularity.

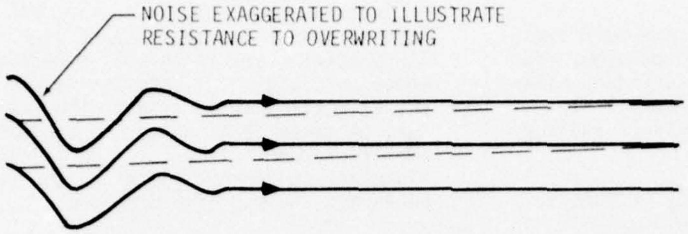
The most common approach, an operational amplifier integrator (Figure 6a), while possessing excellent linearity, suffers from output spikes on turnaround, resulting in deflection ringing. Causes are twofold; input to output coupling through the feedback capacitor and amplifier small-signal bandwidth, both difficult to deal with at the frequencies of interest.

Alternately charging a capacitor from balanced voltage sources (Figure 6b), while free from turnaround spikes, suffers from rate variations. Reasonable charging linearity can be obtained only when the source voltage is much larger than the maximum capacitor voltage.

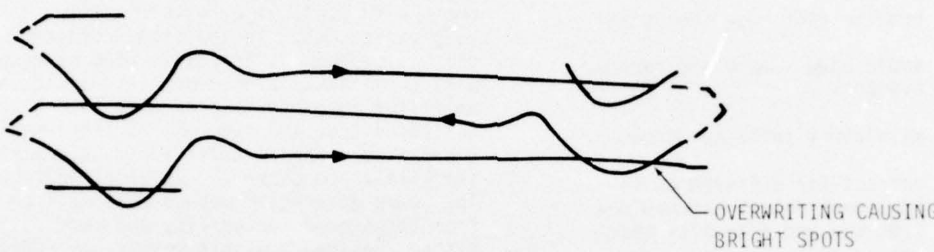
Alternately charging a capacitor from balanced current sources (Figure 6c), offers both good linearity and freedom from turnaround spikes. Practical current sources may be built operating with voltages very near the desired peak capacitor charging voltages. This was chosen as the most suitable method for VITAL.

Dwell time effects on brightness and edge precision weighed heavily in the selection of the VITAL writing techniques from among those shown in Figure 7. Some pros and cons of techniques considered are:

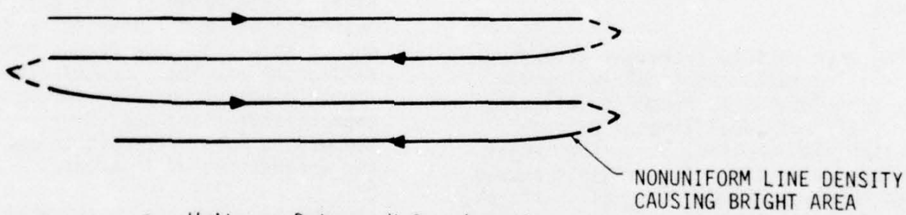
- Vector outline - Good edge definition, but no texture.



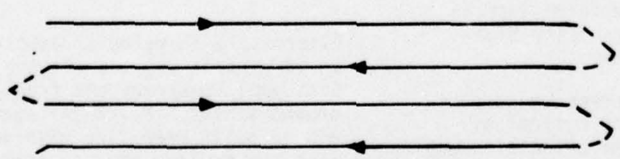
a. Blank on Retrace



b. Write on Retrace-Y Underdamped

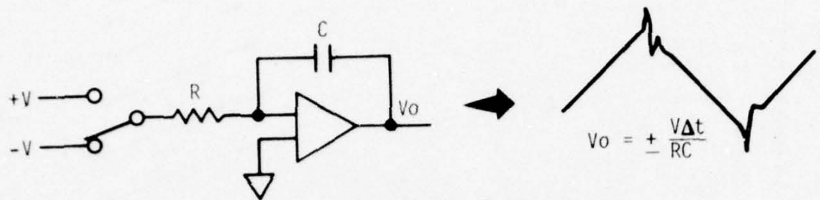


c. Write on Retrace-Y Overdamped



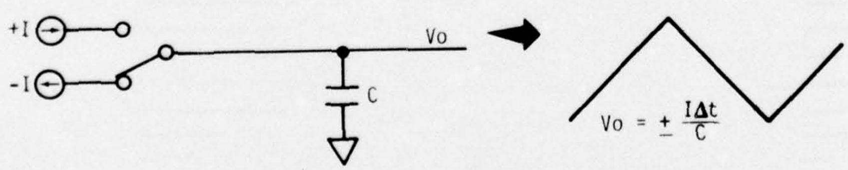
d. Write on Retrace-Y Properly Damped

Figure 5. Effects of Nonuniform Line Density



a. OP-AMP Integrator

b. Capacitor Charged from Voltage Source through Resistance



c. Capacitor Charged from Current Source

Figure 6. Analog Sweep Generation

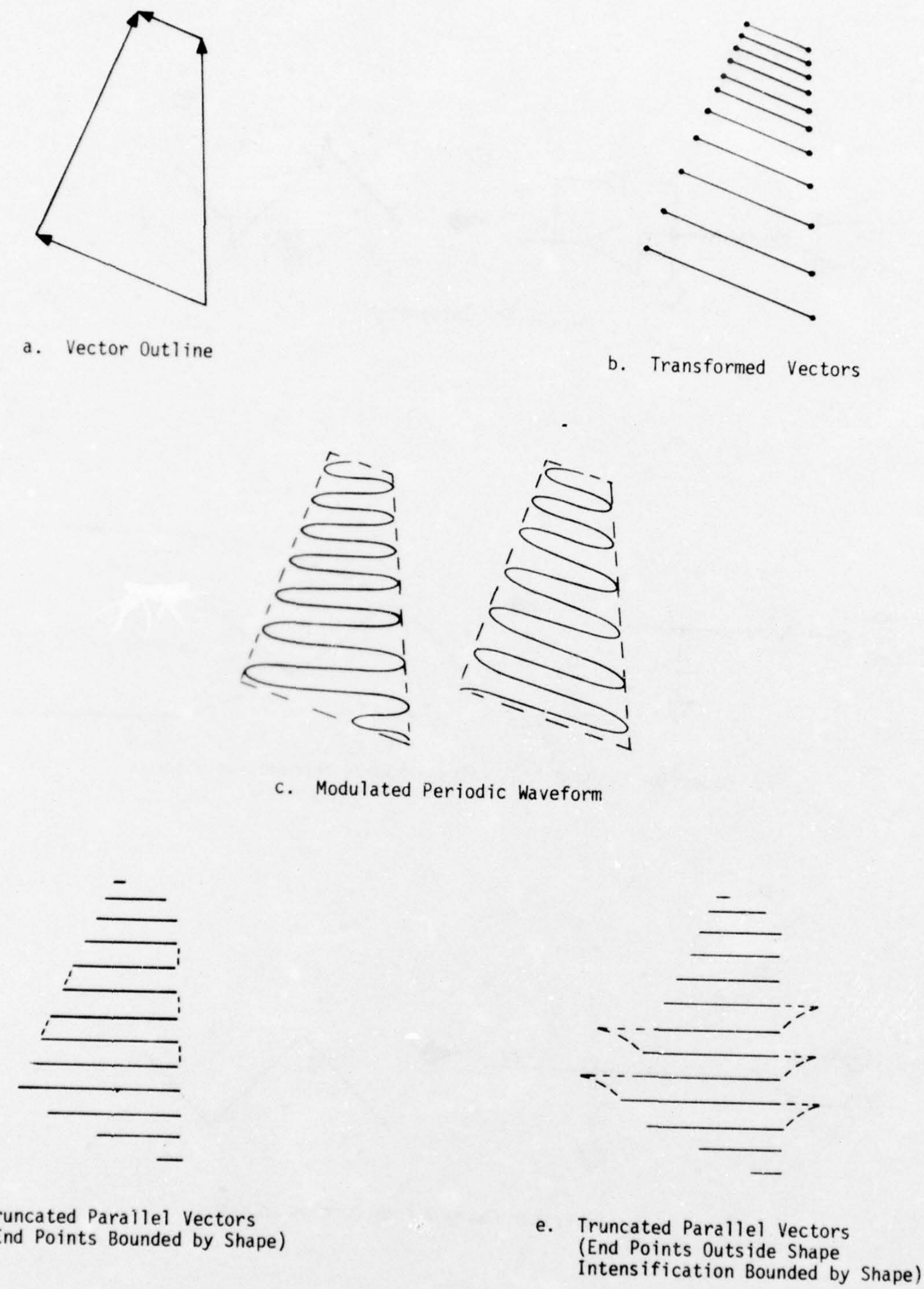


Figure 7. Some Variations of Calligraphic Surface Generation Techniques

- Transformed vectors - Transformation of *individual vectors is relatively* easy. Volume of computations is high. Intensity and precision control is poor because of nonuniform line density.
- Modulated Periodic Waveforms - Better texture and precision uniformity than transformed vectors. Suffers from variable dwell time resulting in brightening of shape edges. Line density varies 50 percent between surface edge and center.
- Truncated Parallel Vectors (bounded by surface edge) - Capable of very uniform texture and brightness except at edge where practical deflection bandwidth limitations restrict beam position control.
- Truncated Parallel Vectors (end points outside surface edges, intensification bounded by edges) - Capable of very uniform texture and brightness over entire surface. Requires precise control of blanking.

The latter approach was taken because of extreme importance placed on surface uniformity Any regular distortion can act as a strong distraction, drawing attention from the scene itself. Blanking control requires considerations that are much more important than for a raster type system. Relative timing between the blanking and horizontal deflection signals is critical. With a raster scan surface, any timing mismatch results in positional offset of the entire surface (Figure 8a). The effect of timing mismatch on a write-on retrace surface is to create a shadow effect on the edges (Figure 8b). The VITAL blanking signal is delayed to compensate for deflection transport delay, thus removing the edge shadow. Blanking delay is adjustable to compensate for individual deflection variations.

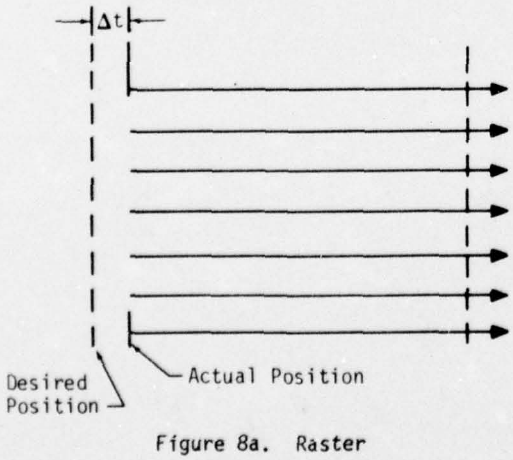


Figure 8a. Raster

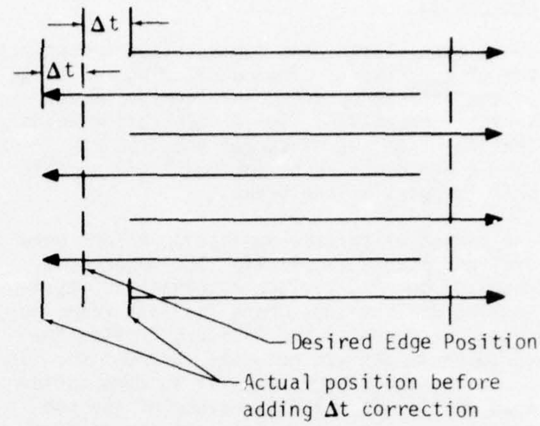


Figure 8b. Write or Retrace

Understanding the nature of deflection transport delay is necessary for proper delay compensation. The horizontal deflection chain gives the dynamic effect of a multiplicity of low-pass filters. Figure 9 gives the output of a simple low-pass filter with a ramp input. The output follows the input by one time constant except near the origin, where there is distortion. The blanking delay compensates for the combined time constants. Distortion near the origin produces a variable delay which could result in different matching requirements for small and large shapes. Deflection overscan is used to linearize the output before unblanking, minimizing delay variations. A tradeoff must be made between amplifier bandwidth (f_2) and overscan time, reduction of overscan requiring an increase of bandwidth. VITAL deflection bandwidth is sufficiently high to make linearity compensation delay a secondary factor.

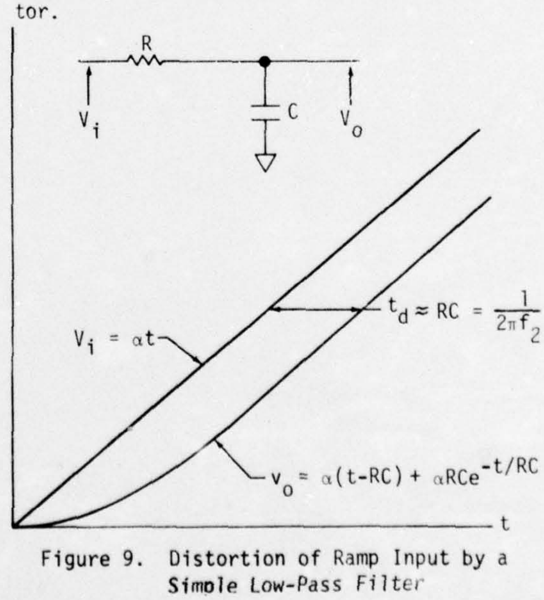


Figure 9. Distortion of Ramp Input by a Simple Low-Pass Filter

CONCLUSIONS

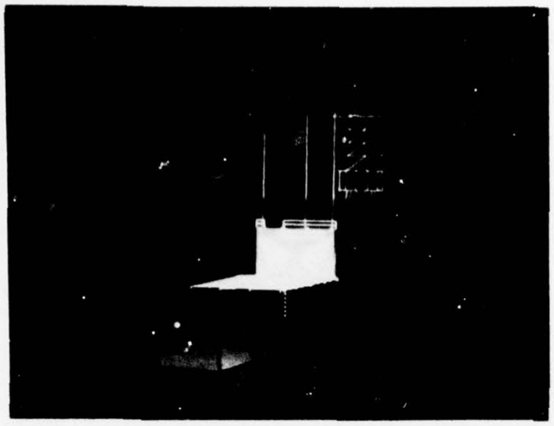
The Raster Blaster has demonstrated a distinct set of advantages. The outstanding advantage is the efficiency of serial lightpoint and surface generation. Serial generation means that the same set of common electronics may be used to generate each lightpoint and surface which appears in the scene.

The method of surface generation offers several advantages in itself. The compressed description of a surface by equations representing its outline, means low data rates between the computer and Blaster, freeing the computer to perform necessary processing. In addition, the effective split in computation load permits more efficient use of the computer's capabilities. The computer performs the relatively complex job of surface outline transformation and windowing, while the Blaster performs the simple but time consuming operation of incrementally generating the surface outline. Thus, for a given amount of computation power applied, a more complex scene may be produced.

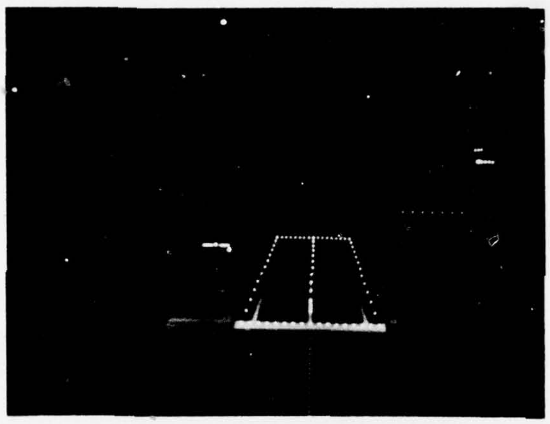
Uniform surface texture gives the appearance of solidity. Combined with computer controlled intensity taper, defined differently for each surface, illusion of depth is enhanced, producing an unexpected degree of realism.

The Blaster has not yet realized its full speed potential. As needed, effective system speed may be increased through improvement of the computer and display electronics. Computer improvements include expansion and the addition of special-purpose processing electronics. Display speed improvements can be made by upgrading the deflection system.

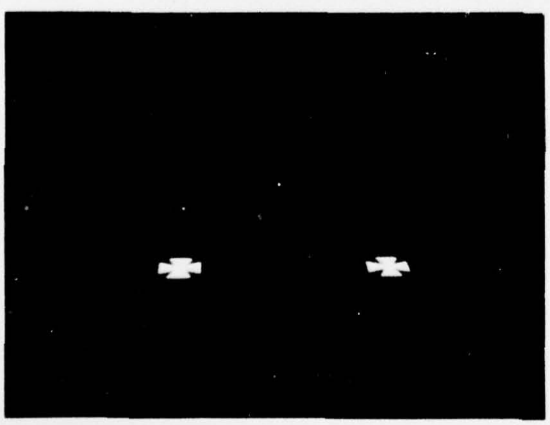
What was designed as a solution to the specific problem of takeoff and landing simulation has rapidly found application in a diverse and growing set of pilot training areas. A few application scenes are pictured in Figure 10. Ongoing research indicates that this new and yet open-ended technology is due to produce some pleasant surprises in the near future.



a. Helicopter Capable Fast Frigate

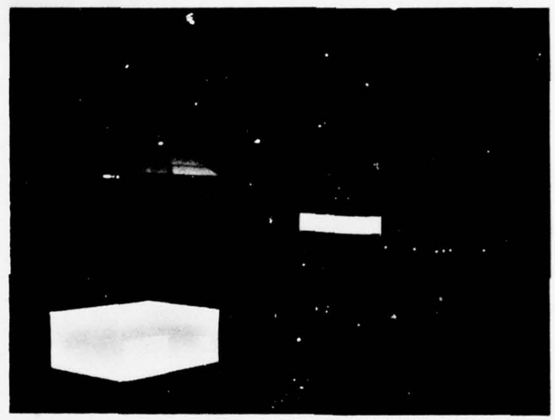


b. Carrier Landing Scene, JFK

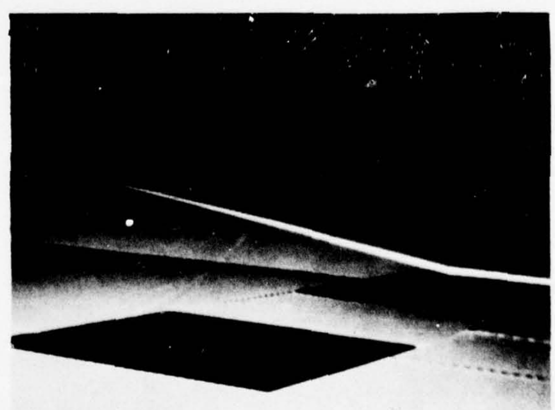


c. Multiple Runway Helicopter Staging Area with Maltese Cross Touchdown Zone Markers

d. KC-135 Aerial Refueling Scene



e. Helicopter Staging Field with Tower and Building in Foreground and Helicopter Landing Pinnacle in Background



f. Daylight Scene with Random Field Pattern

Figure 10. Vital Applications

ABOUT THE AUTHOR

MR. CARL J. VORST is a Senior Engineer at McDonnell Douglas Electronics Company and is responsible for development of the visual imaging electronics which are the heart of the VITAL series visual simulation equipment. Previously, his responsibilities included system design of a Digital Radar Landmass Simulator, and other assignments in the area of system interface technology. Mr. Vorst received a B.S. degree in Electrical Engineering from the University of Missouri.

PERSPECTIVE ERROR IN VISUAL DISPLAYS

ROBERT ENTWISTLE and NEIL MOHON
Naval Training Equipment Center

Perspective in photographic reproductions is one of the most important visual cues to a human observer primarily because it is almost always used subconsciously to make some determination about the photographed subject. Many photographs, especially in the advertising industry, introduce significant errors in the perspective of the object; but that error is rarely detected by the conscious mind of the observer.

Consider the example photographs of an automobile shown in figure 1. The two pictures were made with the automobile in exactly the same location relative to the background scene. However, quite a different impression is relayed to the mind from figure 1a than figure 1b. Figure 1a was made using a 200 mm focal length lens on a 35 mm camera, while figure 1b was made using a 35 mm focal length lens on the same camera. Advertising photographs are often made using short focal length lenses in order to make the car appear longer, more attractive, or to emphasize some particular detail.

One basic anomaly in our "advertising oriented" mind is that we accept the erroneous perspective of figure 1b without question. Maybe we expect it. The next time you see an automobile advertisement, or any advertisement, consciously look for the errors in perspective.

The problem in perspective arises because we do not view the photographic records from a proper distance, or viewpoint. Figure 1a will yield correct perspective when viewed from 60 cm; and figure 1b will be correct when viewed from 10 cm.

When we consider the environment of a military training simulator in conjunction with its ultimate purpose, it becomes imperative that we give careful attention to perspective and the impression it makes. In a simulator the trainee is frequently called upon to make rapid judgments about range, relative size, or rate of movement of a target based solely upon a photographic type display. Obviously the scene should have as little error in perspective as possible in order for the trainee to make accurate estimates. Hence, perspective is a factor in the training value of a display.

We have designed two photographs to illustrate this concept and they are shown as figure 2. The two people are located in exactly the same relative positions in both photographs; and yet there is a dramatic difference in the apparent perspective presented to a viewer. Figure 2a was made using a 200 mm focal length lens on a 35 mm camera; and figure 2b was taken using a 50 mm lens on the same camera. If two situations, similar to figure 2, were presented to a novice trainee in a simulator, it is quite possible that he would make erroneous judgments in range and/or relative positioning. If a target were moving from position A to position B, the judgment of the trainee as to velocity and direction of movement could easily be distorted for the two situations.

We observe from figures 1 and 2 that perspective is the angular relationship between objects in the scene as viewed from the camera position. When a picture is made from a relatively short distance from the objects, the angular relationship between the objects is greater than if the picture were made from a longer distance. The perspective in a picture is exactly correct when the relative angles in the photographic reproduction are identical to the camera viewpoint angles that existed in the original recording geometry.

The correct viewpoint distance, and hence the correct viewing angle, may be derived from the optical relationship inherent in the camera-projector-observer system. Figure 3 represents the entire system from the object, O, through the camera, through the projection (or enlarger) apparatus, and to the observer at the viewpoint, V. The angle subtended by the object is given by

$$\tan a = h/s, \qquad (1)$$

where h is half the object height and s is the object to camera lens separation. To maintain this angle, a, at the viewpoint, we require that

$$h''/d = \tan a. \qquad (2)$$

Equating 1 and 2 and solving for d, the correct perspective viewpoint, we find

$$d = h''s/h. \qquad (3)$$

From the magnification relationship of the projector, we know

$$m = \frac{h''}{h}. \qquad (4)$$

Using this in equation 3, we find that

$$d = mh' s/h. \quad (5)$$

From the magnification relationship of the camera, we know that

$$h'/h = -s'/s, \quad (6)$$

or that

$$s' = -h's/h. \quad (7)$$

Now substitute equation 7 into 5 to yield

$$d = -ms'. \quad (8)$$

The lens imaging equation states that

$$1/s + 1/s' = 1/f, \quad (9)$$

or rearranging

$$s' = f/(1 - f/s). \quad (10)$$

Now, substitute equation 10 into 8 to find

$$d = -mf/(1 - f/s). \quad (11)$$

But, in cameras, it is almost always true that $s \gg f$; therefore, we say that

$$\boxed{d = mf} \quad (12)$$

where we have absorbed the negative sign into the magnification factor, m. Equation 12 states that the viewpoint distance, d, of a photographic recording for correct perspective is found by multiplying the focal length, f, of the recording camera lens by the magnification, m, of the projector (or enlarger) system. Note that this viewpoint must be on the optical axis as shown in figure 3 in order to maintain the correct angular relationships.

Usually a photograph or projected image is not or cannot be viewed from the correct perspective distance (d). The actual distance from which it is viewed we will call distance (D), and we will define a new parameter, Perspective Error Ratio, as

$$PER = d/D \quad (13)$$

Or, substituting equation 13 into 12,

$$\boxed{PER = mf/D} \quad (14)$$

Where the actual distance viewed (D) is larger than the correct perspective distance (d) we obtain a number larger than one, and where it is smaller we obtain a number smaller than one. Multiplying PER by 100 we may obtain a value for the percent perspective error (PPE) which may be useful in some descriptions.

We have used the concept of perspective error ratio to analyze a simulator in which riflemen are taught marksmanship against a series of targets approaching them on a wide front. The requirement involved ten trainees firing onto a wide-angle screen for accuracy score. Figure 4 illustrates the configuration of the simulator. One constraint required that the trainees be positioned along a straight line 25 meters long and be able to fire completely across their 50 meter front. Because we had to have satisfactory screen brightness, good resolution, and a minimum screen size, we wanted to move the screen as close as possible. The result was a cylindrical screen of 30 meter radius having viewing positions generally indicated by the three dots 0m, 10 m, 20 m, to represent respectively positions on-axis, 10 meters off-axis, and 20 meters off-axis. From the 0M on-axis viewing position, the screen subtends 30^{o} on each side of the optical axis.

Figure 5 illustrates the PER across the 60^{o} screen for each of the three positions of figure 4. The perspective error ratio for position 0m, which is directly under the projector lens, is one everywhere on the screen; i.e., this is the position defined by equation 12 above. The PER, from equation 14, varies considerably across the screen for the other two positions and is not linear. The errors in perspective are greatest when the trainees are firing across the screen to the opposite corner of the simulator. As of this writing, there are no definitive results as to the tolerable limits of PER in a training simulator -- or any photographic type scene. So our approach is to minimize perspective error as much as possible by pushing PER toward one while fulfilling the system requirements. We know of no published information on the effects of perspective error on a trainee's learning and/or accuracy. To date, the best approach has been to make some assumptions from acceptable perspective error in portrait photography and apply them to this simulator; all of which may or may not be valid.

Perspective is a significant visual cue in the display of a training simulator because it is needed to make accurate estimates of range, size, and velocity of objects in the viewed scene, and is normally used in a subconscious manner. We have introduced the mathematical concept of perspective error ratio as an approach to measuring and evaluating the perspective in a scene. And we have introduced a graphical type analysis of perspective error ratio to easily study the perspective error in a display. We propose that the next step is to produce standard objects for measuring experimentally the perspective error in a display and determining what tolerable limits can be placed upon such errors for various type simulators.

Figure 1a. Perspective of 200 mm focal length lens on a 35 mm camera.

Figure 1b. Perspective of 35 mm focal length lens on a 35 mm camera.

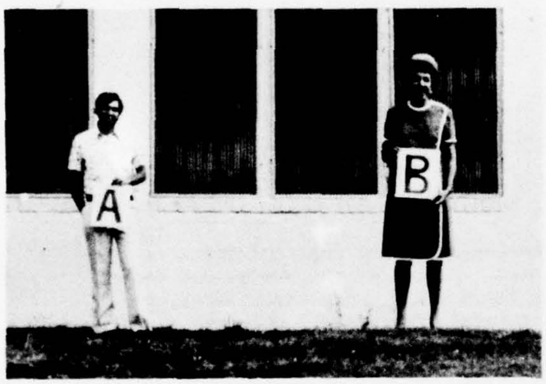


Figure 2a. Perspective of 200 mm focal length lens on a 35 mm camera.

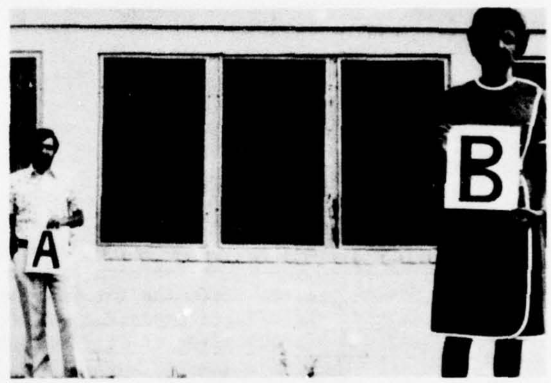


Figure 2b. Perspective of 50 mm focal length lens on a 35 mm camera.

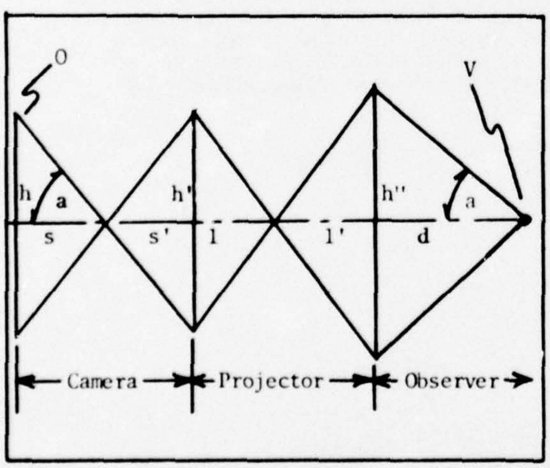


Figure 3. Viewpoint for correct perspective.

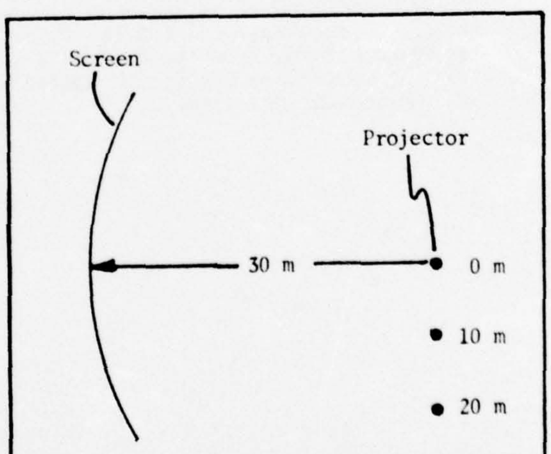


Figure 4. Simulator configuration with three representative viewing positions.

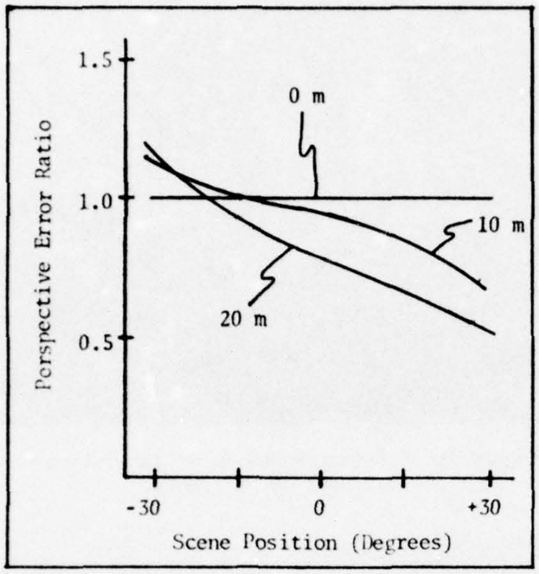


Figure 5. Perspective Error Ratio (PER) as a function of scene angle for three viewing positions.

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COMPENSATING FOR FLIGHT SIMULATOR CGI SYSTEM DELAYS

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Naval Training Equipment Center

INTRODUCTION

Modern flight training simulators are usually equipped with digital computers that measure the pilot's control activities, determine the simulated aircraft's responses, and provide student performance data for the instructor. Recent developments have made it possible to extend digital processing techniques to the generation of visual images, allowing an entirely computer-controlled training environment where a flight dynamics processor calculates the responses of a simulated aircraft and a computer generated imagery (CGI) system presents the changing visual scene to the pilot via a graphics display.

Digital control systems can encounter timing problems when their processing involves numerous calculations. In the past, the time taken by a digital machine to compute the dynamics of a flight simulation has not been a serious constraint on the use of simulators. With the addition of CGI systems, however, *the delays imposed by calculation* times are having an effect on simulator utilization. The temporal sequence of information flow needed to update a computer generated visual scene is depicted in Figure 1. Usually two processors are used; one to control the simulator and one to do the graphics processing. The simulator controller measures the pilot's control inputs, calculates the new aircraft position, and makes the new position available to the graphics processor. The CGI system then obtains the new position of the simulated aircraft and calculates a new visual image to represent it. Present simulation systems can measure the operator's control inputs at rates of 15 to 32 samples per second, allowing aircraft position information to be available with minimal delays ranging from 66 to about 31 milliseconds. Currently available CGI systems take about 100 milliseconds to update their images, creating total system delays from approximately 100 to 200 milliseconds between the measurement of the pilot's inputs to the simulator and the visual presentation to him of its response. Actual delay values may vary slightly depending upon when the dynamics processor makes the results of its calculations available to the CGI system.

The problem introduced by adding a CGI system delay to delays already created by the dynamics processor of a simulation system was highlighted in Device 2F90, a TA4J Operational Flight Trainer, when it was noticed (after the addition of a CGI visual system) that flyers of the trainer tended to produce pilot induced oscillations on the last leg of the carrier approach task. In that device, the severity of these roll-axis oscillations was reduced by changing the aileron response to control stick deflection, but oscillations were still encountered, especially if a large roll input was made during the last 1/8 mile of the carrier approach (O'Conner, Shinn, and Bunker, 1973; or Harris, 1975). A similar situation was encountered using the Advanced Simulator for Undergraduate Pilot Training at Williams Air Force Base. Test pilots experienced an undesirable roll-axis instability during the landing approach and formation flying tasks (Larson and Terry, 1975). Presumably this is due to that device's 126 to 193 millisecond total transport delay.

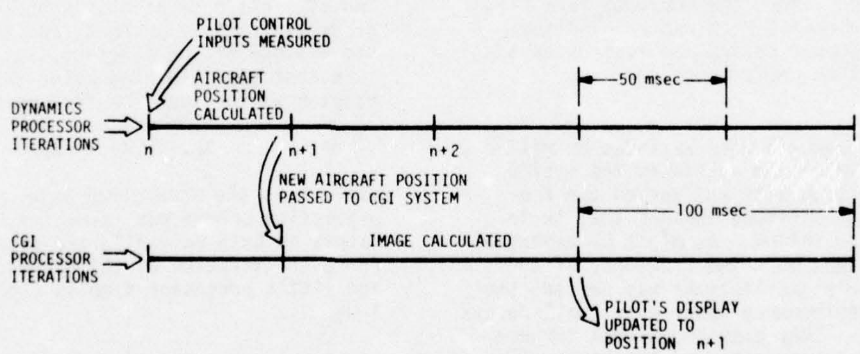

Figure 1. Sequence of Calculations in a Typical CGI Display System.

Recent Work

The effects of inserting various types of delays into feedback control systems that contain human controllers have been studied for some time, and it is well recognized that the presence of delays affects the controllability of systems. Air Force sponsored studies on first-and second-order lags and on transport (dead-time) delays indicate that the control of compensatory systems that have random forcing functions is affected by any type of delay, but that transport delays, which allow no system response for the duration of the delay, are most disruptive. Because pilot performance is affected by short delays, the reduction of the effects of transport delays in the visual systems of flight simulators is an important consideration.

Research at the National Aeronautics and Space Administration Langley Research Center has assessed the effects that small transport delays have on pilot performance when those delays were inserted into the visual display of a flight simulator. Queijo and Riley (1975) had experienced controllers perform a "following" task in a fixed-base simulator where a "target" aircraft underwent slow sinusoidal oscillations of altitude and the task was to follow the target. Dead-time delays ranging from 50 to 300 milliseconds were inserted before the visual display. The amount of delay that could be tolerated was found to be related to ratings of the flying qualities of a variety of simulated aircraft. Only small delays could be allowed in high-performance aircraft simulations before their presence was objectionable and flying performance suffered. When the subjects flew simulations of aircraft with better handling qualities, longer delays had less of an adverse effect on performance.

These results were extended by Miller and Riley (1976) who activated the motion base of the simulator and varied the frequency of the altitude changes that their pilots had to follow. As might be expected, they found that when the frequency of the target plane's oscillations was raised, the subjects' performance under even small delays became poor. They also found that the use of the motion base extended the range of delays that could be easily accommodated. The demonstration that either the handling qualities of the simulated aircraft or the difficulty of the flying task can determine the extent to which dead-time delays can disrupt performance indicates the need to develop compensations for CGI visual systems. As we try to simulate more sophisticated aircraft or to teach the more complicated flying tasks, we might expect display delays to be increasingly detrimental.

At the Naval Training Equipment Center, Cooper, Harris, and Sharkey (1975) have measured the differences in piloting performance that display delays produce. Using the TRADEC F-4 simulator and a carrier landing task, they measured the amplitude spectra of the forces and deflections that experienced pilots exerted on the simulator's controls in the presence and absence of a 100 millisecond visual system delay. By subtracting the spectra obtained under no-delay conditions from similar spectra obtained under the delay, they obtained a difference spectrum for each control axis. This spectrum presents the differences (across frequency) of the pilot's control inputs that characterize control in the presence of a 100 millisecond delay. Information of this nature is useful as it indicates where in the frequency domain action can be taken to compensate for the effects of delays.

The Prediction Problem

As the dynamics processor iterates, it calculates a series of values with the aircraft's present position being represented by the most recent calculations. In practice, a running estimation of a value for the next member of this series, X_{n+1}, can be made by placing the most recent term, X_n, and the immediately preceding terms, X_{n-1}, X_{n-2}, etc., into a prediction equation of the form:

$$X_{n+1} = X_n + f \text{ (multiple terms)}.$$

The most recent term, X_n, is given the most weight and a set of other terms are used to adjust X_n to approximate the future value. The simplest case of this approach is a linear prediction scheme where X_n and the instantaneous slope of the function, $\dot{X}_n$, are combined such that the predicted value is a linear extension of the function from point X_n:

$$X_{n+1} = X_n + K\dot{X}_n,$$

where K is the prediction span. This type of prediction scheme has value for flight simulators as both X_n and $\dot{X}_n$ are usually available for each iteration of the dynamics processor, and little processor time is used to calculate X_{n+1}.

An obvious, simple, and quick formulation, linear prediction has been used where CGI system delays have existed, and has involved an adjustment of the aircraft position values before they are passed to the graphics processor. A problem arises because $K\dot{X}_n$ is a product, so that if either K or $\dot{X}_n$ becomes large, the adjustment to X_n can also become large. The potential for this condition exists in simulations of responsive, high-performance aircraft and/or where the CGI

system has long processor delays. Usually the processor delay remains constant, and the use of a linear projection scheme results in an amplification of the high-frequency responses of the simulated airframe. For aircraft responses which are low in frequency, the predicted value of X_{n+1} does not change much from one iteration of the dynamics processor to the next, but the amplification of the high-frequency responses produces values for X_{n+1} that can fluctuate quite a bit, causing a "jitter" in the visual display. Test pilots evaluating simulators have found the degree of this jitter annoying (Larson and Terry, 1975), and when they were allowed to vary the temporal extent of the linear extrapolation, they adjusted K to a fraction of the true CGI system delay.

This brings us to the real problem in compensating for CGI system delays, and that is the development of a rule for limiting the amount by which X_{n+1} is allowed to differ from X_n. If an aircraft parameter is allowed to change too slowly, the simulation will appear sluggish relative to the real aircraft, but on the other hand, if the rate of change is too high, the visual display will have reduced acceptability because of the imposed jitter. Since the visual system delay is relatively constant for a given system, we have decided not to limit the interval over which a parameter will be projected, but to reduce the amount that a compensation scheme can amplify high-frequency responses by passing adjusted parameters through a low-pass filter. To see if such an adjustment sequence has any utility, we have developed and evaluated a delay compensation scheme that represents the least complex example of this approach, where the extrapolation for the entire delay from X_n to X_{n+1} is linear and the low-pass filter is first order (i.e., has a 6dB per octave attenuation rate above the break frequency).

The Present Effort

Our efforts to develop compensations for visual system delays of the sort found in CGI systems have involved two approaches. In preliminary experiments, we found very little decrement in the performance of a tracking task in which a 200 millisecond delay had been inserted. At about this time, the Cooper, Harris, and Sharkey study found that differences in performance measures such as trials-to-criterion were almost nonexistent for experienced pilots. We suspected that this result was obtained because the experienced pilots had developed the ability to quickly assess the dynamics of the system they were controlling and to change their style accordingly. This feeling was reinforced by their second experiment where differences of measures of the pilots' control inputs were found between the delay and no-delay conditions. We felt that experienced subjects might not be best for the assessment of delay compensations developed for flight trainers, but that they would be ideal for the definition of the limits of piloting control for a given simulator under given conditions. Thus, in order to develop compensations for display delays, we used a two-stage procedure where the effects of experimental manipulations were tested using subjects familiar with the control tasks and the training usefulness of the developed compensation was assessed using naive, untrained subjects.

Control performance under a variety of conditions was measured by having either trained or naive subjects "fly" the system depicted in Figure 2. The compensatory display was an oscilloscope configured to represent an artificial horizon, and the subjects entered their control inputs via a two-axis spring-centered, side-arm control stick. Two types of aircraft, designated Task 1 and Task 2, could be simulated. The

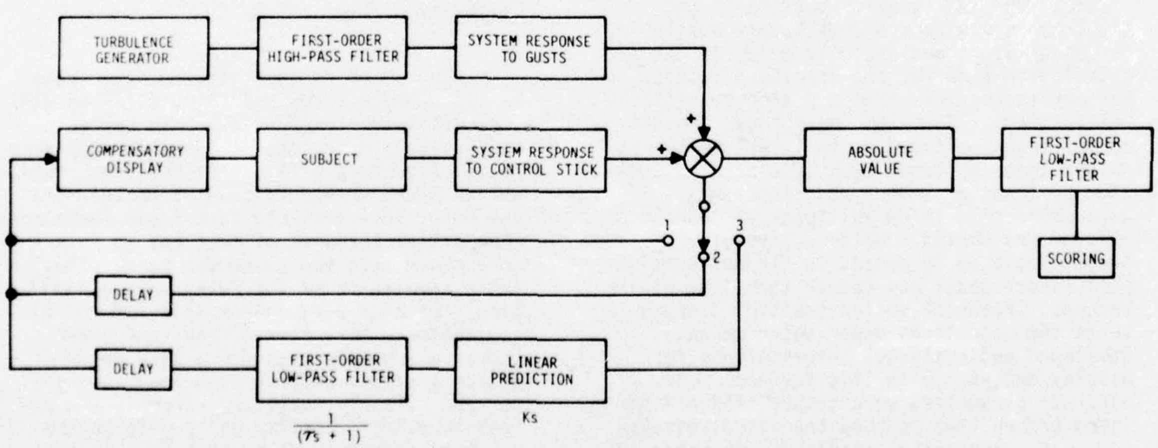

Figure 2. Block Diagram of the Control System and Experimental Conditions.

dynamics of Task 1 were representative of flying a general aviation, light, twin-engine craft, while Task 2 represented flying a high-performance jet interceptor. For both tasks, the subjects were asked to control the horizon indicator so as to maintain a straight-and-level attitude in the face of mild turbulence.

At the end of each two-minute trial, measures of the subject's control performance were available from the scoring system. Models of piloting control suggest that pilots adjust the size and timing of their control inputs to make the system-plus-controller conform to certain requirements, and our measures were chosen to reflect those adjustments (see McRuer, Graham, Krendel, and Reisener, 1965). In the first two experiments where subjects experienced with the system dynamics were tested, the absolute system error, the size of the control stick deflections, and their relative spectral power within a frequency band in the pilot "crossover" region (two to six radians/second) were measured. These measures were integrated and averaged over the length of a trial. In the third experiment, where naive subjects were trained, trials-to-criterion was added to the measure set. Criterion performance was expressed in terms of the displayed pitch and roll error of the aircraft, and, to be considered "trained," the naive subjects had to be able to maintain the system pitch and roll errors under 1^{o} and 3^{o}, respectively, for two consecutive trials. For our tasks, this represents a high-performance criterion, although the experienced subjects were able to generate average error well below these limits.

The three-position switch in the error feedback loop of Figure 2 indicates the conditions under which data were collected. When the switch is in position 1, the error signals from the dynamics portion of the simulator software are immediately available to the display, and the only delay is the calculation time for the displayed values. For our tasks, this time averaged to be 17.5 milliseconds. Changing the feedback switch to position 2 allowed us to insert transport delays into the loop. Our simulation iterated 20 times a second, and these delays were programmed to be multiples of that 50 millisecond period. While delays of any length could be inserted, we did not examine performance under any longer than 1400 milliseconds. Feedback switch position 3 represents the conditions under which we have developed and evaluated compensations for display delays. With this feedback loop, aircraft parameters were compensated and delayed before they reached the visual display. For each experimental condition, the span of prediction was equal to the display delay.

RESULTS OF EXPERIMENTS

Experiment 1

Our first interest was to see how the insertion of a display delay affected our performance measures. In the first two experiments, subjects' control performance was indicated by three scores. The error which a subject produced was used to reflect how controllable he found the system, and the stick deflection and relative power scores were used to indicate the control technique he used to generate that error. Experienced subjects were used in these two experiments, and their data are presented as individual functions in the resulting graphs. In this experiment, performance under a variety of delays was observed, and our control measurements for Tasks 1 and 2 are plotted separately in Figure 3. Only measurements for roll-axis control are presented as almost no differences were seen between delay and no-delay conditions for the control of the pitch axis.

From the plots of system error at the top of the figure, several trends are evident. Controllability gets worse with long delays, and good control is harder for the higher performance aircraft. Both of these results are as one might expect. In addition, however, our subjects displayed large and consistent individual differences. On both tasks, some of the subjects generated up to twice the error that others did, and the rank order of their error scores does not change from the first task to the second.

The stick deflection measure shows a pattern similar to that obtained from the error scores. Subjects who initially made large stick deflections responded to small delays by reducing the size of their control movements, but eventually larger and larger control deflections were needed to cope with the longer delays.

Our third measure, the relative power in the crossover region, shows striking differences between subjects. Some subjects hardly changed the extent to which they were making movements within this frequency region while others showed large differences. As the delay inserted into Task 1 was lengthened, the initial response of some was to insert more power into the crossover band. They later removed it as the delay became still longer. Our high-performance task did not allow subjects this flexibility, and power scores which were high for a zero delay displayed a steady decline with lengthening delays. Clearly subjects differ in the extent to which a display delay affects the accuracy and style with which they control even a simple flight simulation.

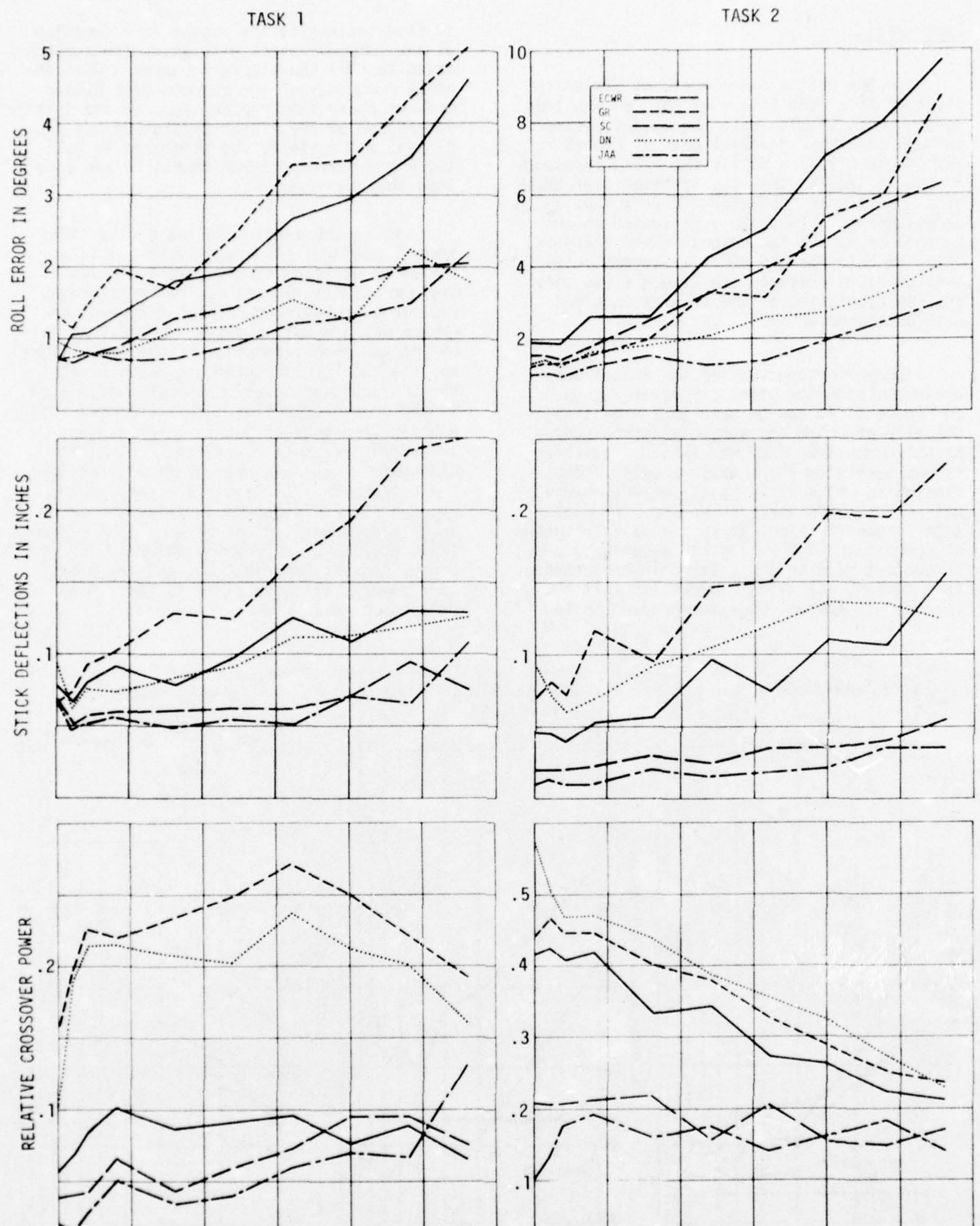

Figure 3. Experiment 1: Control Measures as a Function of Magnitude of Display Delay.

Experiment 2

In the second experiment, we varied the point at which the filter of our compensation scheme began to attenuate the values passed through the third feedback path of Figure 2. This would allow us to fix the break frequency of that filter so that the training usefulness of a good linear predictor-filter scheme could be determined. Subjects were tested on the control of Task 2 for several fixed delays. Only the data for the 400 millisecond delay condition are presented in Figure 4, as they are representative of the results obtained with both shorter and longer delays.

Break frequencies for the filter were chosen to span the pilot crossover region. In Figure 4, it can be seen that this systematically affected the subjects' error scores. As the break frequency was raised, the error scores became smaller, up to a point. This finding is not surprising as subjects cannot null error which they cannot see. In addition, these functions appear to have a minimum at about four to five radians/second, as some subjects tended to increase their error above that region. It is our impression that the increase of system error seen above the four to five radians/second region is a function of the compulsiveness with which the subject tried to null the displayed error. When the break frequency of the compensation filter was set above that region, some of the "jitter" introduced by the linear prediction was displayed, and subjects who attempted to null the high-frequency error tended to add more than they removed.

As in the first experiment, the other control measures responded systematically. The stick deflection scores went through a minimum between four to six radians/second, and for some subjects, a high-frequency increase was present. As the compensation filter passed more components of the error signal and the display appeared more responsive, the subjects increased the power they placed in the crossover region. This occurred until a break frequency of two to three radians/second was reached; beyond that point, the crossover power remained relatively constant. The dotted lines of Figure 4 represent the average value of each measure for the zero-delay condition. It can be seen that a break frequency can be chosen for which the system error, the stick deflection, and the crossover power scores are close to their non-delayed values.

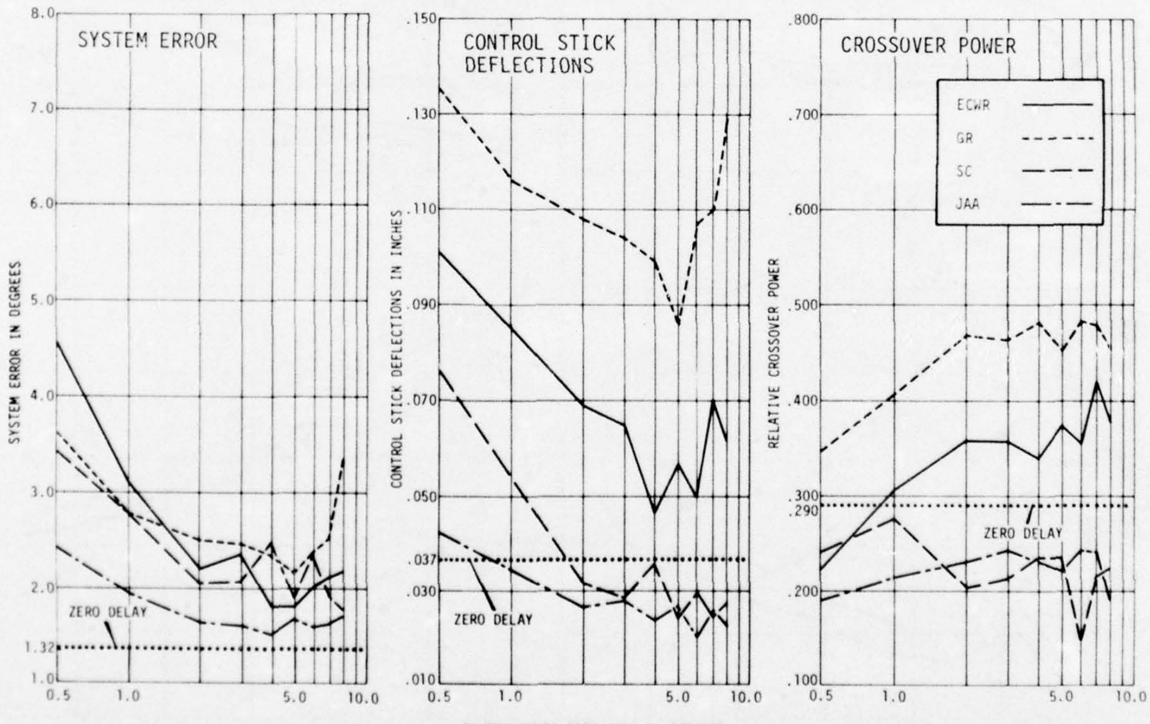

Figure 4. Experiment 2: Control Measures for Task 2 as a Function of Break Frequency of Compensation Filter. Inserted Delay Equals 400 Milliseconds.

Experiment 3

In this experiment, we decided to fix the break frequency of the compensation filter and determine how inexperienced subjects would acquire the control skill under delayed or delayed-and-compensated conditions. This experiment was designed as an acquisition and transfer study where subjects first learned to control the display using the Task 1 dynamics and then were transferred to Task 2. A delay with or without the linear prediction and filter was inserted into Task 1 and our main interest was in the training time (trials to criterion) that the various conditions required. Since we were also interested in how subjects would respond on a new non-delayed task, all subjects were asked to perform at least one trial on the transfer task. This task contained no delay and was performed after criterion was reached on Task 1. Our testing sessions had a twenty-trial limit so that they could be easily scheduled, and this required that subjects reach criterion on Task 1 by at least the nineteenth trial.

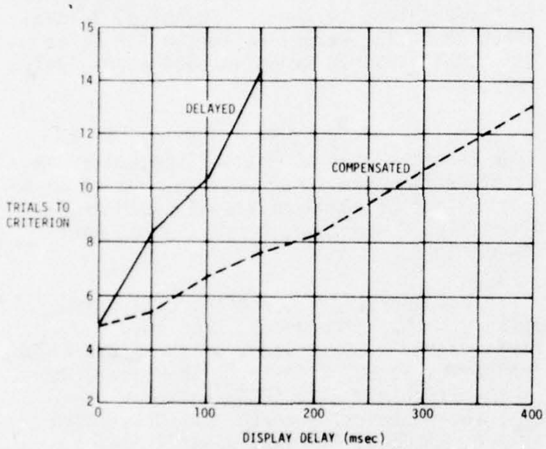

Figure 5. Experiment 3: Mean Trials to Criterion for Task 1. Break Frequency of Compensation Filter set to 4.5 Radians/Second.

Figure 5 presents the trials-to-criterion data for conditions that represent all three positions of the feedback switch in Figure 2. The training time necessary to master our normal undelayed system is presented as the zero-delay point, and the time needed when delays from 50 to 150 milliseconds were inserted into the feedback loop is presented in the upper function marked "delayed." Conditions where the display delay exceeded 150 milliseconds were not thoroughly tested as many subjects did not reach criterion within the nineteen-trial limit. The lower function labeled "compensated" presents the data collected using the third feedback loop of Figure 2. Here the break frequency of the compensation filter was fixed at 4.5 radians/second, and with this filter setting, display delays of up to 400 milliseconds were included in the experiment.

Clearly the amount of practice needed to reach criterion performance increases as longer delays are inserted into the feedback loop. It is also evident that training time is increased at a lower rate when the delay is compensated. Both plots seem to be simple linear functions of the magnitude of the display delay.

It is possible that acquiring the control skill under a particular delay condition might encourage subjects to perform in ways unique to that delay. So, to test for this possibility, we analyzed (across delay conditions) the control measures obtained on the last acquisition and the first transfer trials. Differences of these measurements on the last acquisition trial would indicate whether subjects developed different styles of control to produce criterion performance, and differences on the transfer trial would indicate if subjects trained under various delay conditions would control differently on a standard undelayed test. Our subjects were trained to an error score criterion so we expected that the measurements of system error would not differ, and they did not on either the acquisition or transfer trial. In addition, no differences were seen across delayed or compensated conditions in the stick deflection or relative power scores. Apparently having subjects meet a strict performance criterion forced them to be homogeneous in their control style, and it merely took them longer to master the skill when a display delay was present. Using the delay compensation reduced the training time necessary for this mastery.

CONCLUSION

From these experiments, several conclusions can be drawn which may affect the use of flight training simulation systems that contain CGI system display delays.

1. Addition of a low-pass filter to the linear prediction scheme appears to have overcome the limitations of that technique and to have significantly increased its training usefulness. Linear estimation of future values of aircraft parameters is greatly improved by removing the "jitter" associated with that technique with an appropriate filter.

2. In flight training systems that contain significant dead-time display delays, equivalent trainee performance can be produced using fewer training trials if this form of delay compensation is used. Even with this rather simple compensation approach, a 40% reduction in training time was achieved by making an adjustment for a display delay.

The reduction may be further increased by tailoring the compensation scheme to a particular control axis of the airframe or to the requirements of a given flying task.

3. When subjects train on one system and then go to perform on another, there is always the question of transfer. In the case of CGI system delays, there is the potential that trainees will learn to "fly the simulator" and will acquire skills under conditions of a display delay that will produce negative transfer for nondelayed tasks. Happily, our data indicated no evidence of this tendency, and we suspect that it was because the subjects were trained to a performance standard. If a training program allows a fixed amount of training time where not all of the trainees may acquire the skill at the same rate, negative transfer effects may appear.

4. The error tolerances that served as training criteria in our third experiment were both narrow and constant throughout a trial. For some flying tasks, such as carrier approach or weapons delivery, performance tolerances become progressively more narrow as the task progresses. In contrast, tasks such as formation flying or aerial refueling demand narrow performance tolerances over an extended period of time. While a compensation for CGI system delays is potentially useful in all areas of flight simulation, we would expect that improvements resulting from the use of such a scheme would be more dramatic for tasks of the latter category.

5. The filtered linear projection scheme seemed successful enough to warrant further work on delay compensations tailored to flying tasks. The difference spectra of Cooper, Harris, and Sharkey's study appear to have a 12 decibel per octave high-frequency attenuation rate, suggesting that we can change our low-pass filter to a second-order one, allowing its break frequency to be set higher while still attenuating the high-frequency responses strongly enough to reduce the display "jitter" to acceptable levels. Such a change may not affect measures such as the system error, but it should be reflected in higher test or instructor pilot ratings of the acceptability of a simulation.

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MICROPROCESSOR CONTROL OF HIGH-SPEED PIPELINE SIGNAL PROCESSORS

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ABSTRACT

Schedule constraints, availability requirements, functional equipment modularity, and cost are driving the design of high-speed pipeline processors. This paper describes the evolution of signal processor products for radar and sonar trainers that has led to the adoption of microprocessor controlled implementations.

INTRODUCTION AND SUMMARY

In the past decade, DOD concepts for radar and sonar training have evolved from simulation to stimulation of actual operational equipment.[1] This has placed an extreme burden on the signal processor for speed and flexibility. All present day trainers use digital/analog pipeline techniques for signal processing. This paper describes the evolution of radar and sonar signal processor developments that have been driven by cost, schedule, and availability. Examples of design philosophy have been drawn from sonar training devices 14E19, 14A2, 14E23, 14E25, 14E27, and future sonar product ideas; and from the USAF Undergraduate Navigator Training System (UNTS) radar trainer, along with future radar trainer ideas.

In summary, microprocessors are here to stay, and the total design process has evolved toward "programmable logic." With the ten-dollar microprocessor system available today, the "old" days of equipment design are gone.

REQUIREMENTS AND AVAILABILITY HISTORY

The program requirements of cost and schedule have caused the system modeling, algorithm development, and hardware design to be performed in parallel. At the same time, the equipment complexity has increased by ten every three to four years; the availability has increased from 75 percent to 95 percent, with the MTTR decreasing from 2 hours to 20 minutes.

The preceding requirements have caused the modularity of function and hardware, the flexibility, and the built-in test capability to increase, until we have the present microprocessor-controlled architecture of the 14E27 Sonar Operator Trainer. This design philosophy, using seven functional subsystems, allows the signal processor control programs to be loaded during final checkout, saving redesign and rebuild time. Also, each microcontroller is being used autonomously for signal processing control, built-in test, and checkout signal insertion.

Because of the short delivery schedule and trainer complexity, the system definition and modeling, the system software, and the hardware are all being designed in parallel. In the past, this has caused large perturbations in checkout because three dependent areas were being integrated, with each having numerous "bugs." This fact has caused our systems to evolve to their present stages. Now, the hardware is built and checked out independently of the modeling/software and, as these elements are checked out, the hardware may be modified via "firmware change." Thus, the total checkout/acceptance test cost is greatly reduced.

A side benefit is that the microprocessor controller has led to more general-purpose cards and common design, which reduces the design time and leads to system commonality and easier sparing.

GENERAL SYSTEM ARCHITECTURE

The microprocessor controller is a programmable device designed to provide a flexible input/output (I/O) capability with desired stimulus, control, and monitor requirements for a variety of digital systems. With these capabilities, the controller can be built into large digital systems to perform three basic functions of primary concern. First, the controller can provide the control function for special-purpose hardware. This is particularly significant since it means that, in general, the total logic hardware design can be reduced to the design of generic type cards; i.e., data registers, data selectors, counters, adders, multipliers, etc. The timing clocks and mode controls are then furnished by the controller under program control. Second, the controller can substitute an idealized stimulus for test purpose and monitor results to perform automatic built-in testing. Third, the controller can be programmed to provide an idealized stimulus as desired to aid "in-system" signal tracing, which is particularly valuable during initial system checkout.

The controller architecture is similar to that of general-purpose computers in that the CPU consists of a central control unit, arithmetic/logic unit, and program memory. The central control unit itself differs radically, though, from the normal computer control unit, in that the instruction set is allowed to operate directly on various special-purpose I/O registers. Since the instruction execution time is very fast, this allows a high-speed dynamic stimulus capability for external control. Special consideration is given to provide flexibility in the controller for receiving data from the external system for monitoring

purposes. Also, the capability exists to test the level of input control lines that can be used as flags to cause program branches.

In a system that is to use a microprocessor controller, the system partition and design process is as shown in Figure 1. The key to the whole procedure is that the system is partitioned so that each subsystem with microprocessor controller can be packaged in one card rack. This card rack then has a small set of inputs and outputs and performs a total system function.

The microprocessor controller evolution is now leading to more generic designs, autonomous card racks with built-in power supplies, totally ground-noise isolated by optic communication links, bit-slice microprocessor applications, and increases in the level of built-in test functions.

CONTROLLER ARCHITECTURE

The general-purpose controller is shown in Figure 2. The controller is a 16-bit machine capable of executing a variety of instructions, including data transfer, arithmetic, logic, and branch type instructions. Special features include (1) the ability to perform branch instructions, dependent upon a wide selection of internal and externally generated flags, (2) the ability to condition input data registers to meet the requirements of the external device, (3) the ability to gate system clocks to the external system, and (4) the ability to operate from either RAM or ROM program memory. The instruction execution time depends on the master clock. With the master clock in the range of 5 to 10 mHz, all instructions (except transfer immediate) take two times the master clock period; while the transfer immediate instruction may be wired to take one times the master clock period. Below a 5 mHz, all instructions are wired to take the master clock period (e.g., 5 mHz clock given 200 nanosecond instruction time).

The input data registers are 16-bit parallel registers that can be added in increments of three registers, to a maximum of six. Under program control, it is possible to condition each of these registers uniquely to load the register, using either an externally generated clock or an internally generated constant clock. Program instructions are provided, allowing the controller to use the data from the input register.

The four general-purpose save registers serve as temporary holding registers that can be used as desired during program execution. Save register zero also acts as one side of the compare function for comparative branch type instructions.

The ALU functions to perform arithmetic/logic functions on selected accumulators, output registers, or the compare register. The results are then stored back into the designated accumulator, output register, or compare register. All arithmetic operations assume positive data only, and overflow/underflow conditions are ignored.

The accumulation RAM provides 16 general-purpose accumulators that are directly addressed by the program; i.e., specific operations can be performed on designated accumulators. One accumulator is used for compare operations; six are used to control output registers, and the remaining nine function as general-purpose accumulators.

The output data registers are 16-bit parallel registers that can be expanded to a maximum of six registers, in increments of three. The contents of the output data registers can be used directly in arithmetic/logic or shift instructions, since they are copied in equivalent accumulators.

The external clock control provides a means whereby the controller internal clock, or clock divided by two, can be gated to the external device

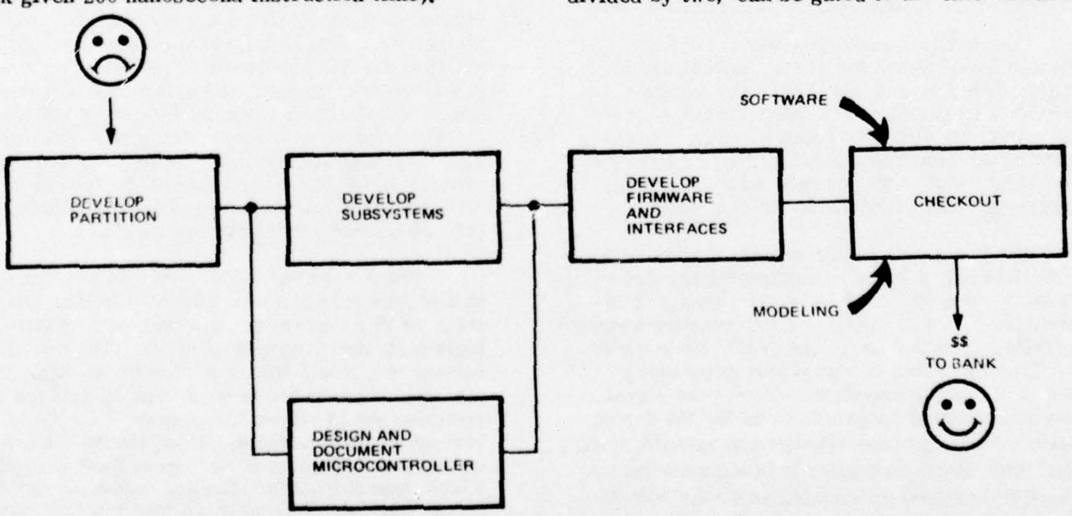

Figure 1. Development Process

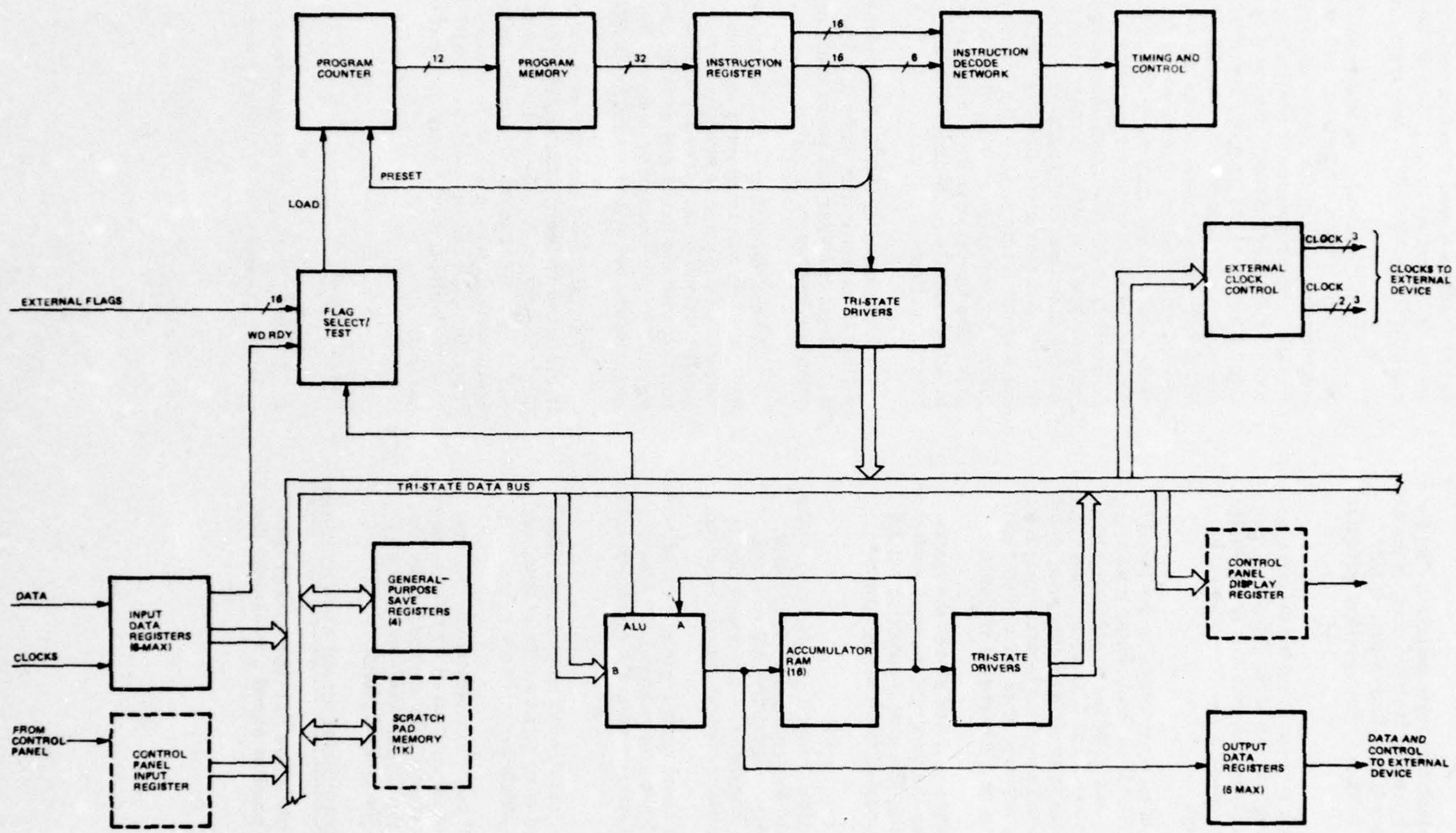

Figure 2. General-Purpose Controller Basic Block Diagram

under program control. This is particularly useful in pipeline type processing.

The flag select/test logic selects a flag for a conditional branch type instruction, and, if the appropriate condition of that flag exists, it will cause a program branch to the specified program address.

The program counter provides the program address to the program memory. Under normal operation, instructions are executed sequentially until a program branch causes the program to alter this sequence.

The program memory contains the coded program in either RAM or ROM units; primarily, RAM for checkout and ROM for production units. The program memory is 32 bits wide, consisting basically of a 16-bit instruction field and a 16-bit data field for use in immediate instructions; i.e., program memory provides data for transfer or specified operation on a designated register.

The instruction register stores the instruction accessed from the program memory such that, during its execution, the next instruction can be simultaneously accessed from the program memory.

The instruction decode logic determines the type of operation to be performed. It decodes which source register will drive that data bus, which destination register to load, which flag is selected, and any other control signals required.

The control panel input register is applicable only if the control panel is provided. It allows the operator to enter data from the control panel to the controller.

The optional scratchpad memory provides temporary storage of up to 1K words of data, and is organized on a single logic board.

The optional control panel display register allows the contents of any source register to be monitored by transferring the contents of the desired register to the display register, which is then displayed on the control panel.

MICROPROCESSOR CONTROLLER APPLICATION

As an example of the microprocessor controller applied to pipeline signal processing, the target processor for the 14E27 trainer will be explained. Figure 3 is a block diagram of the 14E27 Pipeline Signal Function Generator. It is set up and operated by an H-716 Minicomputer, and stimulates an SQR-17 Spectrum Analyzer.

For our example, we will focus in on the Narrowband Target Processor, with the understanding that each of the blocks in Figure 3 also contains a microprocessor controller, and operates in a similar manner. Figure 4 is a detailed block diagram of the Target Processor. At first glance it might appear very complex, but if one follows the input signals across the page, one can see the mathematical operations performed on the data. The unusual features of the block diagram are the General-Purpose Controller (microprocessor) in the lower left-hand corner (in past systems this has been a hardwired controller), and the insertion/sample test data points shown at the GPC and throughout the block diagram. Figure 5 shows a flow chart of the Microprocessor Controller and gives an indication of its operation. The Operational Program uses 84 PROM locations and the Auto-Test Program uses 360 PROM locations.

Also during checkout, programs were written to exercise data paths in a looping test so that a logic analyzer and scope could be used to debug the hardware.

A note of caution; at the beginning, a total loop auto test was tried for a while and failed because of diverse and interactive errors. Finally, small portions of the circuitry were exercised, starting with the inputs and working toward the output. In this systematic manner, the whole unit was checked out in a short period of time.

The microprocessor is destined to be used in all future trainers and DOD equipment. This paper has shown that the evolution of the Pipeline Signal Processor (because of cost, schedule, and availability) has been driven to a microprocessor controller that can provide operational control, perform built-in test, and aid in the checkout of the unit.

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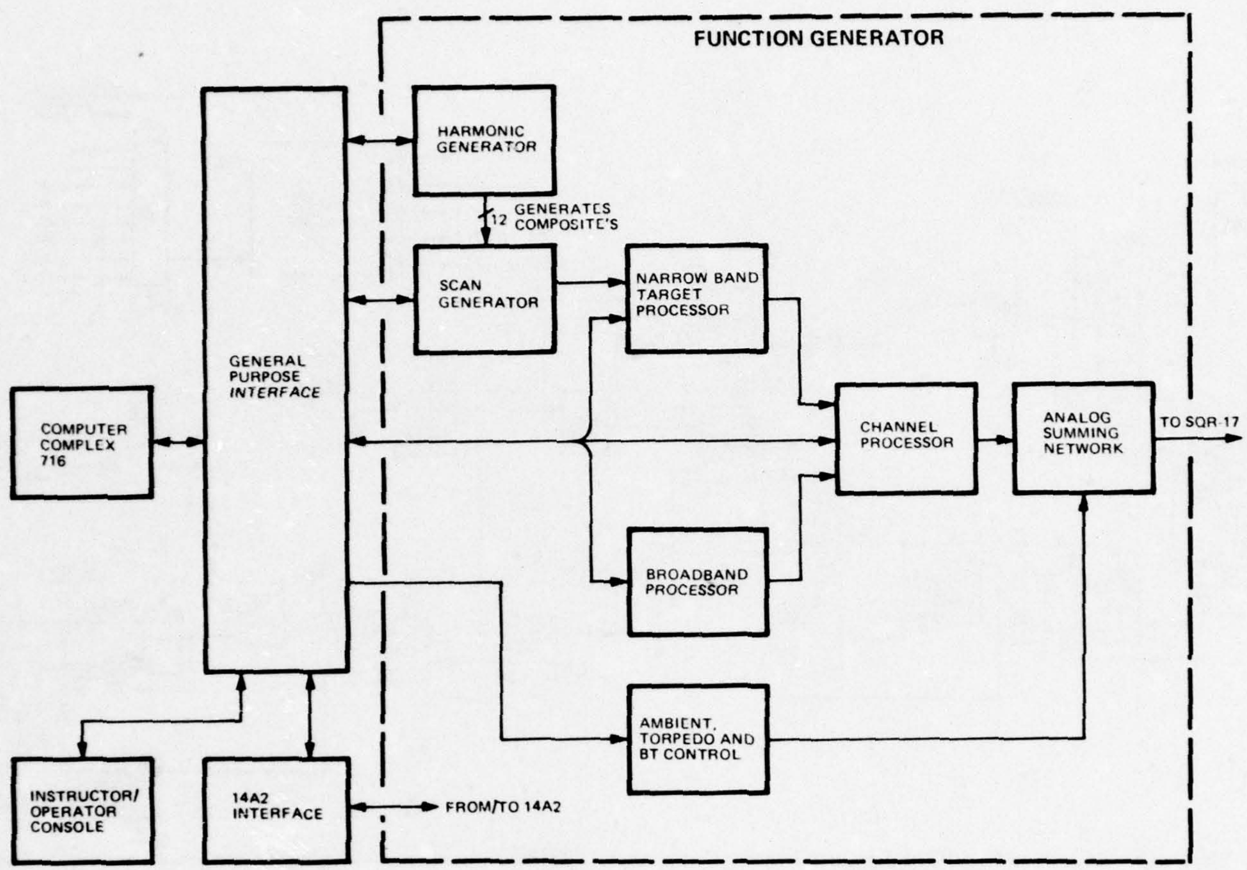

Figure 3. Device 14E27 Function Generator Basic Block Diagram

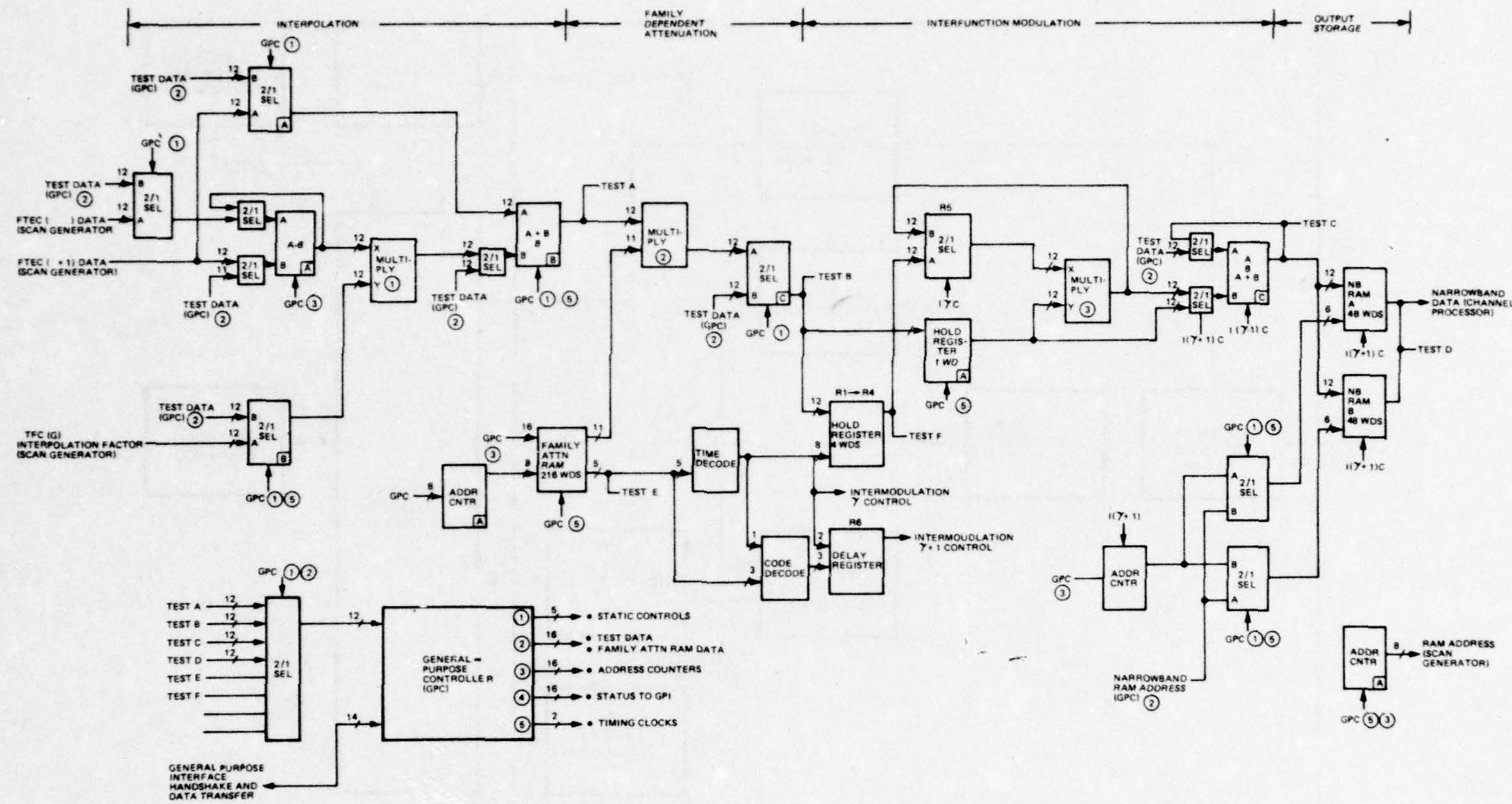

Figure 4. Target Processor Block Diagram

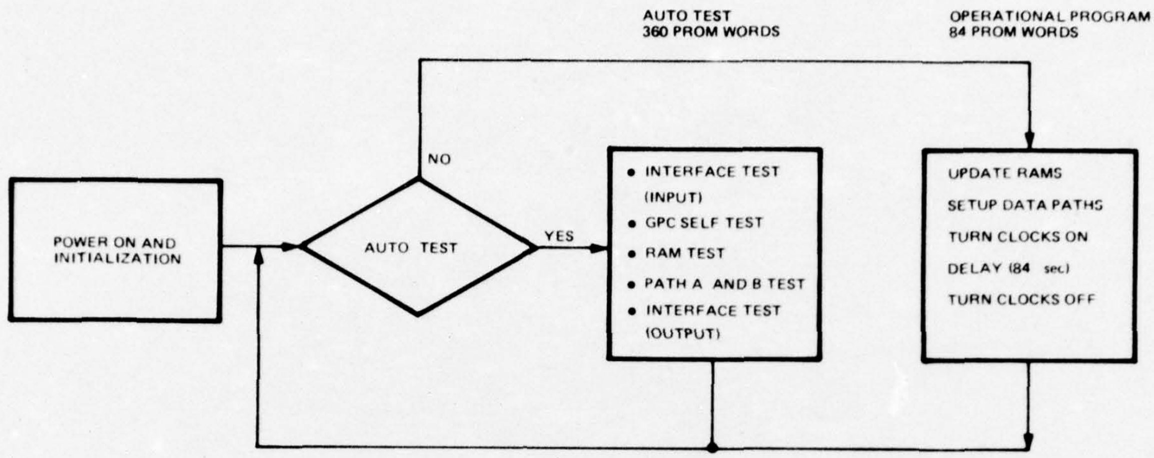

Figure 5. Firmware Flow Diagram

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MR. DARREL K. HADLEY is a principal design engineer with Honeywell Marine Systems Division. He is the lead digital design engineer for Device 14E27. Mr. Hadley is responsibile for the digital design and checkout portions of Device 14E27, and coordinates the digital design effort with systems engineers. Mr. Hadley earned his B.S. and M.S.E.E. degrees at the University of Colorado.

A MOTION SENSING MODEL OF THE HUMAN FOR SIMULATOR PLANNING

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INTRODUCTION

The conventional use of simulators for flight research, be they moving base or fixed base, has involved an attempt at reproducing some aspects of face validity without determining either the requirements for such validity or the aspects of the simulation which are really important in either research or training. Limited knowledge of the physiological sensing mechanisms, especially for the perception of motion, has forced upon the simulation community an acceptance of "expert pilots'" opinions as the *sine qua non* of simulator design and acceptability. Yet, very rarely do two pilots agree on all aspects of a simulator's fidelity. With the development of better models of physiological processing of sensory signals and a framework for their use based upon modern control theory, we are now in a position to improve upon this situation for simulator planning. This paper describes a number of parallel research efforts (Ref. 1), which are being carried out by the Air Force Human Resources Laboratory, to (1) improve the basic physiological subsystems descriptions and (2) integrate these subsystems into a model for simulator planning. It is anticipated that such a model will not only aid in the planning of simulators but also possibly become a major portion of the simulator's drive logic.

CONVENTIONAL VIEW

Current simulation methodology is based upon an open loop strategy as depicted in Figure 1. The assessment, other than through pilot opinion, is typically on the basis of closed-loop control. Does the pilot "do the same thing" in the simulator as he does in the real aircraft? Since the adaptability of the human pilot makes such closed-loop performance criteria relatively insensitive to the simulation fidelity, they are not particularly convincing. The conventional method is to simulate the aircraft's flight equations in real-time on a computer and to use the aircraft state variables to drive separately a visual display, instruments, motion platform, sound system, and any G-cuing devices. Each of these systems is commanded to reproduce as accurately as possible the sights, sounds, and feel produced by the corresponding aircraft situation. The assumption is that the pilot will be provided the best overall simulation if he is presented with individual sensory modalities, each of which is tuned to reproduce the real world situation as best as possible within the limitations of cost and mechanical drives. Relatively little effort has been paid to the question of how to best compromise any one of the simulation modalities or how to best combine the

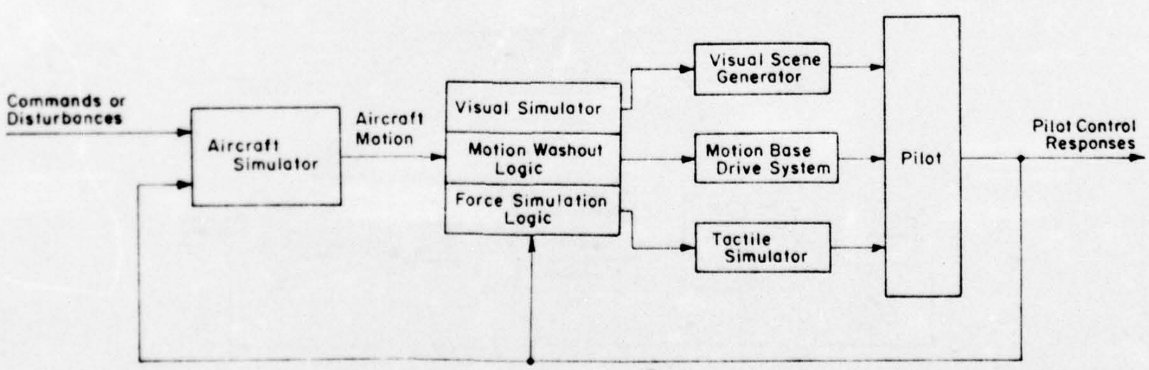

Figure 1. Current Simulation Design Method Based on Duplicating Aircraft Motion

different sensory input simulations to produce an overall effect which is better than that produced by working with them individually. For example, the question of the influence of moving visual fields on the requirements for low frequency cab motion drives is an important factor, one which is not addressed by this design philosophy. A limitaticn of the conventional design philosophy is, in our opinion, the concentration on faithfully reproducing aircraft motions and force rather than reproducing pilot sensations.

THE "PILOT SENSORY MODEL" APPROACH TO SIMULATOR DESIGN

If we assume that the goal of simulation is to produce the same sensations of motion and force in the pilot during the simulation as he would receive during actual flight, then one is led to a design configuration illustrated in Figure 2. Underlying this philosophy is the existence of an adequate model, the "multisensory motion sensing model of pilots" which predicts, in at least a statistical sense, the pilot's perception of spatial orientation based upon defined visual, motion, and force inputs occurring individually or in combination. This model is applied to the actual aircraft situation being investigated to determine what the pilot's perceptions would be in the aircraft. It is then also applied to the proposed simulator output to predict what the errors in perception would be. Simulator visual, motion, and G-cuing drive algorithms may then be designed to produce simulator output within the mechanical limits of the equipment which will minimize this error in perceived orientation. Clearly, the major weakness in this design philosophy is the lack of adequate multisensory motion sensing models. Attempts to remedy this situation are a part of our current research. As indicated in Figure 3, we are treating perceived orientation as an optimum estimator problem in which a Kalman filter estimates the perceived orientation based on the outputs of the various sensory systems each of which is assumed to have a characteristic dynamic response and associated additive noise. The models for sensation of angular velocity attributable to the vestibular senses are relatively well developed. Even complex motions, involving possibly contradictory information presented by the otoliths and semicircular canals, can be treated by such models (Ref. 2). Similar models for foveal visual inputs, which basically relate to instrument readings, have been developed and require only application of the appropriate fraction of attention divided to each instrument to be applied (Ref. 3). Peripheral visual information which leads to perceived changes in orientation or angular rate are being developed on the basis of work on visually induced motion (Ref. 4). The greatest area of uncertainty is in the processing of tactile and proprioceptive information. Data from these systems will be most important in determining stimulation and drive requirements for G-cuing devices, including G-seats, G-suits, and seat shaker systems. We are currently using both psychophysical and physiological data to try to develop both the high and low frequency characteristics of these sensory modalities and to achieve appropriate noise levels so

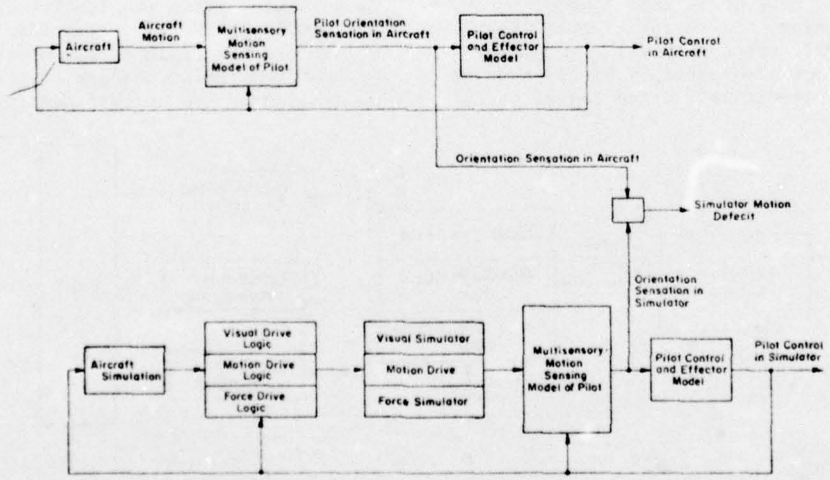

Figure 2. Schema for Simulator Specification and Control Based on Pilot Sensory Systems Models

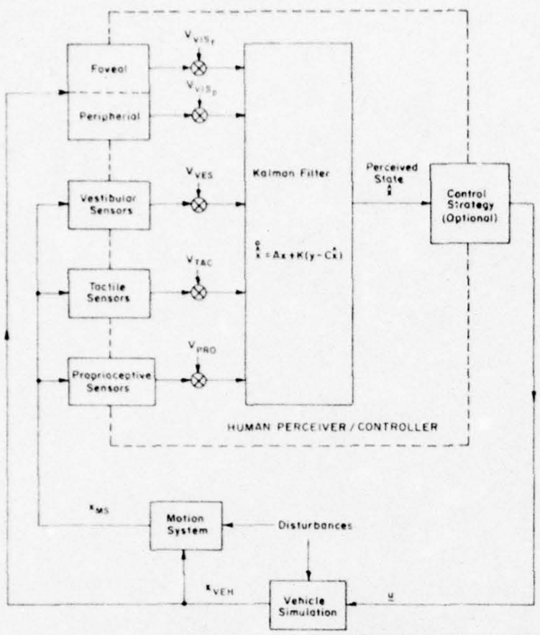

Figure 3. Block Diagram of Model for an Optimal Processor for Perception

that they may be integrated in the Kalman filter and blended with the other sensory modalities. In addition, it must, of course, be recognized that the pilot is engaged in an active flying task. Consequently, some means must be made of placing into the context of this model the pilot's expectation of aircraft response on the basis of applied demands.

It is our hope that the eventual application of pilot models based upon underlying physiological mechanisms will provide a rational way of simulator planning to provide the pilot with the minimum amount of simulator hardware required to give an adequate reproduction of orientation sensations for either training or research simulators. Furthermore, it is our goal to incorporate such a motion sensing model into the conventional simulator drive algorithm to facilitate the optimum performance of the device. Results from the modeling effort are anticipated in early 1977.

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PILOT PERFORMANCE MEASUREMENT SYSTEM FOR THE A-7 NIGHT CARRIER LANDING TRAINER (NCLT)

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ABSTRACT

Vought Corporation - Systems Division is under contract to NAVAIR (4131) to develop a pilot performance measurement system that will aid the Landing Signal Officer (LSO) during training in the A-7 Night Carrier Landing Trainer (NCLT). This paper discusses (a) how parametric performance data (lineup and glideslope error, sink rate, airspeed, etc.) are collected on categories I and II A-7 replacement pilots during NCLT and night carrier qualifications, (b) how the data will be statistically analyzed to determine those factors that indicate student progress, (c) how these factors will be combined into a single predictive index, and (d) how the program products can be applied as training aids. Finally, the results of preliminary analyses are presented.

INTRODUCTION

The Vought Corporation - Systems Division is conducting a Night Carrier Landing Trainer data collection program for the Naval Air Systems Command (AIR-4131) under Contract No. N00019-73A-0010. The objective of the program is to develop valid computer-scored measures of student pilot progress in the NCLT. These measures are also to be explored for their predictive value in the field carrier landing practice (FCLP) and the carrier qualification (CARQUAL) environments. The resultant measures are to be incorporated into a student pilot trend analysis summary printout as a training aid to the Landing Signal Officer (LSO) community.

Vought is currently contracted to, (a) develop and install an automatic data collection system in the NCLT, (b) collect quantitative NCLT and CARQUAL performance data on 60 A-7 replacement pilots, (c) collect questionnaire data and qualitative LSO student performance comments and records for the 60 replacement pilots, (d) perform preliminary analyses on these data, and (e) recommend NCLT training aids.

Preliminary performance measures, grading boundaries, and training aid formats have been developed for the data collection system. At this time, the data collection system has been implemented at NAS LeMoore, California, and is operational. The data collection effort is complete. The results of preliminary analyses indicate a predictive relationship between NCLT and CARQUAL performance exists and that a more in-depth analytical effort should be undertaken to validate the system and to develop the desired program products.

Figure 1 is a simplified overview of data collection, data analysis and program product relationship. Shown are the data from two samples (development and validation) of 30 replacement pilots (RP's) going through the NCLT-FCLP-CARQUAL cycle. These data are then shown to be analyzed for the ultimate development of the program products - a grading system and an instructional strategy (training aid). Data collection, analyses and validation, and training aid development are discussed in later paragraphs.

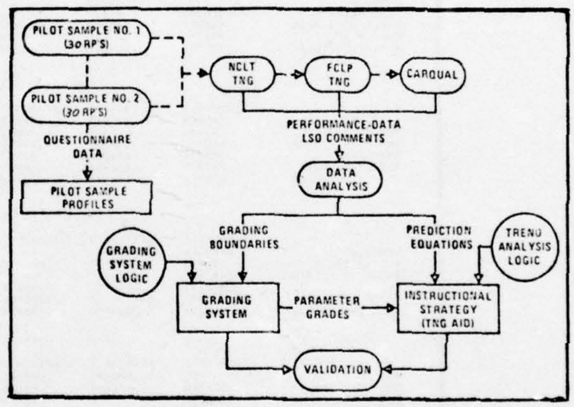

Figure 1. Overview of Program

Preliminary Performance Measures

The initial candidate performance measures selected included lateral and vertical error, sink rate, and airspeed at specified intervals (3/4, 1/2, 1/4, 1/8 NM and at the ramp). These measures were selected because they are the only measures that can be collected through the carrier ACLS SPN-42 radar system. However, additional performance measures were selected for collection in the NCLT. These include glideslope, lineup, fuel flow, angle of attack and pitch attitude as well as velocity vector and a work response index. The measurement system is designed to continuously sample these parameters from 1 1/4 NM to the ramp, and to print out means and variances for each of six selected segments. Both absolute error data, and error data weighted by range, are considered.

Weighting by range emphasizes the criticality of errors when "close in." Mean percent time in tolerance for the first five of these parameters are also collected across each of the six segments.

The NCLT data collection system printout is shown in Figure 2. The figure shows that the printout includes initial and terminal conditions, record-keeping data, and computed grades for lineup, glideslope, angle of attack, fuel flow and pitch attitude. These grades (0 to 4 scale) are based on preliminary performance boundaries established early in the program and are implemented in the current data collection system.

PILOT: SSN: SQDN: DATE: 4 MAR 79 PERIOD: 0 RUN: 0
LSO: LPS: WIRE: TOTAL RUNS: 10
LSO GRADE: COMMENTS:

TERMINAL PERFORMANCE VALUES

SINK RATE: 12.916 HOOK TO RAMP: 13.188 LATERAL ERROR: -3.125 PITCH ATTITUDE: 8.0230 ROLL ATTITUDE: .49097

INITIAL CONDITIONS

SEA: 0 VISBTY: 42. CEILING: 11800. GUSTS: 0 WOD DIR: 0 WOD SPD: 30. WEIGHT: 21634
A-7E CLEAN CVA-61

MEAN OF ABSOLUTE ERRORS

	SEGMENT 1	SEGMENT 2	SEGMENT 3	SEGMENT 4	SEGMENT 5	SEGMENT 6	TOTAL PASS
LINE-UP	48.03125	6.	3.84375	2.75	1.90625	2.	17.99375
GLIDESLOPE	29.125	1.03125	1.1875	2.34375	1.03125	1.5625	12.375
ANGLE OF ATTACK	1.201437	1.530067	1.066230	.424822	.925429	.999038	1.138092
FUEL FLOW	610.903906	110.966797	49.400391	57.40625	59.687429	60.089844	248.4375
PITCH ATTITUDE	.960999	1.654286	1.418879	.499451	.549719	1.409068	1.120709

VARIANCE OF ABSOLUTE ERRORS

	SEGMENT 1	SEGMENT 2	SEGMENT 3	SEGMENT 4	SEGMENT 5	SEGMENT 6	TOTAL PASS
LINE-UP	186.	17.5	1.	0	0	0	389.25
GLIDESLOPE	524.409375	.90625	.5	.5	.59125	.15625	396.9875
ANGLE OF ATTACK	.486157	.096813	.047841	.017978	.031812	.037966	.347096
FUEL FLOW	292900	930	300	100	90	90	166000
PITCH ATTITUDE	.308994	.105469	.0625	.035196	.25	.007813	.338031

MEAN OF WEIGHTED ERRORS

	SEGMENT 1	SEGMENT 2	SEGMENT 3	SEGMENT 4	SEGMENT 5	SEGMENT 6	TOTAL PASS
LINE-UP	.009405	.001613	.001493	.002046	.002748	.00566	.003426
GLIDESLOPE	.00421	.000972	.000529	.001672	.001777	.004372	.002229
ANGLE OF ATTACK	.00021	.000301	.000425	.000322	.000941	.002635	.0004
FUEL FLOW	.092506	.028992	.020401	.042949	.000785	.160694	.06110
PITCH ATTITUDE	.002517	.006592	.009053	.009791	.019635	.066920	.007178
VELOCITY VECTOR	.000863	.056963	.025869	.027419	.024365	.039929	.033622

VARIANCE OF WEIGHTED ERRORS

	SEGMENT 1	SEGMENT 2	SEGMENT 3	SEGMENT 4	SEGMENT 5	SEGMENT 6	TOTAL PASS
LINE-UP	.0000019	.0000008	.	.0000001	.0000002	.0000008	.0000051
GLIDESLOPE	.0000085	.0000001	.0000001	.0000001	.0000024	.0000002	.0000066
ANGLE OF ATTACK	.00000001	.00000001	.	.00000002	.00000106	.00000006	.00000022
FUEL FLOW	.004639	.000031	.000061	.000107	.000795	.000961	.003109
PITCH ATTITUDE	.00000001	.000000009	.000000007	.000000014	.000001256	.000000019	.000000415
VELOCITY VECTOR	.000049	.000039	.000031	.000065	.00002	.000230	.000093

WORK RESPONSE

	SEGMENT 1	SEGMENT 2	SEGMENT 3	SEGMENT 4	SEGMENT 5	SEGMENT 6	TOTAL PASS
RMS LONG. STK.	1.	.386283	.439963	.25	.75	.395264	.75
RMS LAT. STK.	.935364	1.030762	.720021	1.75009	.399964	0	1.
RMS THROTTLE	1.060608	0	.353516	0	0	0	.60457
ALL	1.995972	1.417009	1.51538	2.00009	1.199964	.395264	2.43457

PERCENT TIME IN TOLERANCE

	SEGMENT 1	SEGMENT 2	SEGMENT 3	SEGMENT 4	SEGMENT 5	SEGMENT 6	TOTAL PASS
LINE-UP	5.915649	100.	100.	100.	100.	100.	61.750595
GLIDESLOPE	59.63095	100.	100.	100.	100.	100.	83.932096
ANGLE OF ATTACK	35.831314	0	1.183426	100.	68.101802	20.	29.376495
FUEL FLOW	96.192764	100.	100.	100.	100.	100.	79.376495
PITCH ATTITUDE	64.265045	15.060226	99.443707	100.	83.333328	0	51.430093
ALL	0	0	1.183426	100.	68.101802	0	15.947235

OPERATIONAL COMPARISON DATA

	3/4 NM	1/2 NM	1/4 NM	1/8 NM	AT RAMP
SINK RATE	9.825986	11.946807	11.820001	10.099947	11.180615
AIRSPEED	136.909397	137.836961	134.330722	133.669434	132.918311
LATERAL ERROR	14.8125	-9.5	-2.375	-2.5	-1.8125
VERTICAL ERROR	-2.9375	1.34375	-2.625	-.90625	2.09125
AOA ERROR	-1.060912	-1.27013	-.706379	-.426466	-1.275082
FUEL FLOW ERROR	131.897492	73.878266	61.930097	42.601563	78.46875
PITCH ERROR	-1.684705	-1.999626	-1.114929	-.909664	-1.619175

GRADES:	LINE-UP	GLIDESLOPE	ANGLE OF ATTACK	FUEL FLOW	PITCH ATTITUDE
	3.90	4.	2.84	4.	0

MALFUNCTIONS: NONE

Figure 2. NCLT Data Printout Format

Preliminary Performance Boundaries

Preliminary boundaries/standards were identified from existing operational data and from handling qualities characteristics of the A-7E. These were refined through evaluation by LSO's and are currently used as the initial set of standards.

At this time, preliminary boundaries have been further refined for glideslope, lineup, angle of attack, fuel flow, and pitch attitude. This modification was based on the results of a group of seven LSO's flying 202 approaches in the NCLT. The approaches were grouped by LSO grade (0.0 to 4.0) and compared with the total sample of mixed grades. Figure 3 illustrates the rationale for boundaries that are being established for all performance measures. This example (based on glideslope performance data) shows how upper

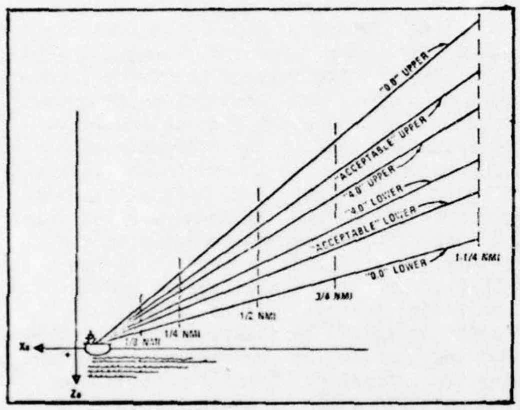

Figure 3. Sample Vertical Error Boundary Rationale

and lower limits for 0.0 through 4.0 grades are established at six points from 1 1/4 NM out to the Number 1 wire. "Acceptable" upper and lower limits are being established by examining three types of data: (a) one standard deviation from the mean error at the "windows" for all approaches (class average), (b) the mean values for a minimally acceptable approach (grade of 2.0) and (c) the region within which LSO comments do not occur.

The initial boundary sets will be updated and refined, subsequent to the completion of the data analysis phase.

DATA COLLECTION

Initial data collection activities involved testing a sample of 7 LSO's from NAS LeMoore (VA-122, VA-125) and NAS Cecil Field (VA-174) in the NCLT to refine the preliminary performance standards. This data collection effort was conducted at NAS LeMoore, California. NCLT predictor and criterion data were collected for the LSO sample during NCLT simulation as currently defined in the A-7 Replacement Pilot NCLT syllabus.

In addition to flying the NCLT, the LSO's have participated in the program in other ways: first, they were consulted to provide subjective information relevant to the rationale behind their descriptive comments and symbology when evaluating a student night carrier landing pass. This information aided in the formulation of a rationale for development of a computerized trend analysis system. Next, the LSO's again flew the NCLT to provide additional flight data for debugging the initial computerized procedures for assessing trends and assigning grades. Finally, the LSO's continue to monitor and assess both NCLT and CARQUAL performance to provide grades.

Data from two separate samples of 30 A-7 category I and category II replacement pilots (RP's) was collected in the NCLT and during CARQUAL to provide a basis for development of the pilot performance measurement system products. Syllabus variations have been minimized by utilizing, for analytical purposes, only those data applicable to the relatively standardized approaches flown during NCLT syllabus periods two through six.

CARQUAL data collection efforts to date included cruises aboard the USS Enterprise, USS Saratoga, USS Nimitz, USS Coral Sea, and the USS Kitty Hawk. Data obtained aboard these carriers included LSO comments and analog traces from the carriers' SPN-42 equipment. These traces include ranges, ship heave and pitch, vertical error, lateral error, airspeed, sink rate and closure speed for each pass. Figure 4 is a partial sample of a SPN-42 strip chart recording for a carrier approach.

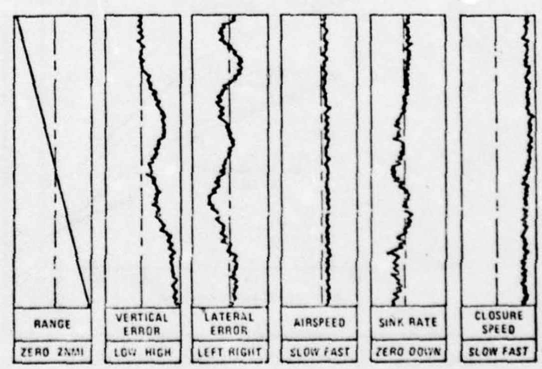

Figure 4. Sample SPN-42 Strip Chart Record

SPN-42 data will be converted to digital form for comparison with similar NCLT data. LSO comment data from both the NCLT and the CARQUAL environments will be used to develop a trend analysis summary as a training aid. This training aid is discussed in a later paragraph.

DATA ANALYSIS AND VALIDATION

The first analytical effort will involve development of normative performance (norms) for each independent variable using NCLT data only. Statistical studies will examine function distribution variances and means to determine those measures which are most descriptive of techniques resulting in good performance. It is anticipated that for some of the measures, mean values may be the most descriptive of normative performance. For others, such statistics as maximum deviation or percent time within tolerance may be more appropriate to predict the number of periods (passes) required by a pilot to reach the criterion performance level as set by the LSO's for NCLT training. The data for making these predictions will be based on pilot flight histories and from NCLT data.

Normative performance values will also be established for final performance measures. These normative performance values will be determined for each of the two RP samples of 30 students, and for the combined sample (60 students). These data (mean errors and standard deviations) will be plotted for the five parameters that comprise the NCLT grading system (e.g., lineup, glideslope, angle of attack, fuel flow and pitch attitude) at each LSO grade level. The plots will be used to establish criteria for grading the parameters. Figure 5 is an example of this type of plot.

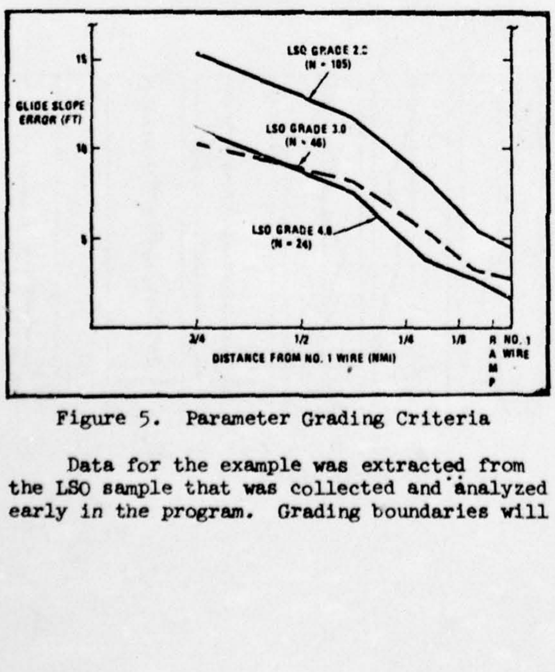

Figure 5. Parameter Grading Criteria

Data for the example was extracted from the LSO sample that was collected and analyzed early in the program. Grading boundaries will be adjusted such that the parameter grades "best fit" the overall LSO grade. The initial boundaries (those currently in the NCLT) will be adjusted during further data analysis efforts.

Subsequent to establishment of final performance norms for each of the performance measures, multiple correlation techniques employing a linear regression model will be used to account for the variance in LSO scores and Landing Performance Scores (LPS). The LPS assesses the quality of a landing on the basis of terminal conditions (wire no., etc.). The objective is to determine the equation which, according to a defined criterion, best describes the dependent variable (LSO grade or LPS) in terms of those independent (predictor) variables that the analysis shows are factors that influence the LSO's evaluation of the quality of a night carrier approach.

It is planned to employ the Efroymson method (Efroymson, 1960 and Rosenthal, 1966) which combines the forward selection (step-up) and the backward elimination (step-down) procedures with a check for co-linearity. The essential idea of the Efroymson method is, of those variables that were in the regression equation at the last step, delete that variable which gives the "minimum nonsignificant (at a specified F-value) increase to the residual sums of squares" and where the multiple correlation coefficient is not significantly large. If no variable is deleted in the first stage, those variables that were not in the regression at the last step are inspected. Among the variables, that variable which gives the maximum significant (judged by the F-test) decrease to the residual sums of squares is added. If no such variable exists, the procedure is finished and the "best" equation has been determined.

Data collected during the program will be employed in the development of the final performance measurement system for the NCLT, based on both CARQUAL and NCLT variables. An intercorrelation matrix will be computed on each of the sample groups of RP's to modify the preliminary NCLT performance standards and grading criteria such that they are consistent with their CARQUAL counterparts. NCLT predictor scores and correlations will be redetermined in these cases where acceptable performance envelopes have been modified. Intercorrelations between segments will also be presented.

Results of the regression equation developed for the first sample group of RP's will be evaluated for effectiveness by using predictor data in the regression equation and comparing predicted criterion data to NCLT and CARQUAL criterion data.

A double cross-validation design will be employed; that is, the data collected on the second RP sample will be used to validate the regression equations developed on the first RP sample, and the data collected for the first RP sample will be used to validate the regression equations developed for the second RP sample. The final regression equations, grading and prediction system, performance standards, and trend analysis forms will be based on all 60 pilot subjects utilizing both NCLT and CARQUAL data. The cross-correlation analysis will be tested for residual or second order effects.

Analysis of LSO Comment Data

An important feature of the NCLT training aid to be developed during this program will be automatic emulation of LSO qualitative comments whenever performance does not meet specified criteria. To establish these criteria, both NCLT and CARQUAL data will be analyzed. For example, if during CARQUAL, the LSO records the comment, "high in the middle" (HIM), the analog trace will be examined for a peak in glideslope error. Both the range of this peak and the corresponding magnitude of the glideslope error will be recorded. This data will be sorted and analyzed to determine how many feet above glideslope the LSO considers to be 'high', and at what range the LSO considers to be the 'middle' of the approach. Subsequently, range and glideslope error thresholds can be established which, if exceeded, will cause an automatic 'high in the middle' comment to be printed. Ranges for the CARQUAL data may be slightly different from those collected from the NCLT. This could occur because NCLT data is being collected at discrete 'windows', whereas CARQUAL data is being collected on a continuous analog trace.

For example, it will be possible to determine the range from touchdown the LSO considers the 'middle' of the pass. (See the vertical dashed line in Figure 6). This value will be determined from the average range of the flagged data. Glideslope error threshold values (shown by the horizontal dashed line) will also be determined. This will be accomplished by selecting a value for the glideslope error threshold that may include, for example, 75% of the flagged data.

It is anticipated that a combination of the glideslope error thresholds from 'high start', 'high in the middle', 'high in close', and 'high at the ramp' comments, will result in more objective glideslope scoring boundaries. These scoring boundaries will be compared to the results of the regression analyses. From these dual analyses, quantitative scoring boundaries will be identified.

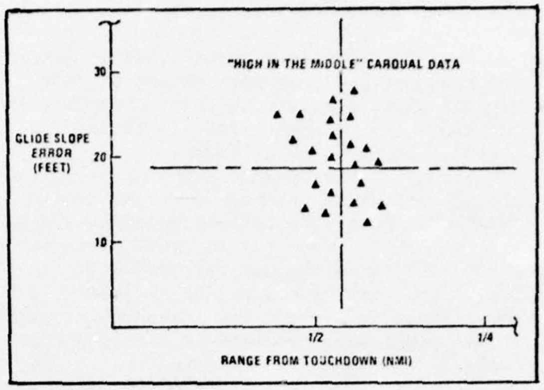

Figure 6. Range Versus LSO Comments

TRAINING AID DEVELOPMENT

One of the products of this program will be an automatic NCLT performance trend analysis printout to aid the LSO in the NCLT training environment. Development of this training aid will be accomplished through analysis of LSO suggestions and from NCLT and CARQUAL data collected during the program. LSO comment data will be examined and compared with digital and analog data to establish boundary values pertaining to specific comments. These data, along with extensive discussion with LSO's, will be used to develop a performance trend analysis printout addressing those elements which the LSO considers critical, dangerous, or unacceptable.

The Current Training Aid Format

The training aid format as currently printed out in the NCLT is shown in Figure 7.

PILOT: SSN: SQDN: DATE: PERIOD: RUN:
LSO: LPS: WIRE: TOTAL RUNS:

PASS	PERFORMANCE MEASURE	STD	GRADE	CALL BALL 0.75 NMI	MIDDLE 0.50 NMI	IN CLOSE 0.25 NMI	AT RAMP
	LINE UP	XXXX	2.96	LEFT	LEFT	***	***
	GLIDE SLOPE	XXXX	3.00	***	***	***	***
	ANGLE OF ATTACK	XXXX	1.21	***	FAST	FAST	FAST
	FUEL FLOW	XXXX	3.60	***	***	***	***
	PITCH ATTITUDE	XXXX	1.0	***	***	NOSE LOW	NOSE LOW
	LSO GRADE		2.0				
	WORK INDEX	XXXX	15.1				
	ACCURACY INDEX	XXXX	41.0				
	CALCULATED GRADE		2.1				

Figure 7. CARQUAL Trend Analysis Format

The specific features of this printout are:

1. Records of such data as pilot's name, SSN, squadron, date, LSO's name, Landing Performance Score (LPS), wire caught, NCLT lesson or period, number of runs for the period, and

the total number of runs to date.

2. Qualitative comments when a parameter boundary is exceeded at one of four windows (3/4, 1/2, 1/4 NM from touchdown, and the Ramp) are printed ('left', 'right', 'high', 'low', 'slow', 'fast', etc.). In addition, the performance score or grade for each parameter is printed under the heading "GRADE." After data collection and analysis are completed, standards for each parameter grade will be determined for evaluating an individual pass, i.e., how an individual's performance in lineup, for instance, compares to the population or standard lineup performance.

3. The LSO grade, LPS, work index, accuracy index, wire caught and an overall calculated grade.

4. Appropriate LSO comments that are entered at the teletype. Four additional discrete performance items or comments will be automatically flagged for use in the printout. These are: "WING ROCK IN CLOSE," "DROPPED NOSE IN CLOSE," "LANDED ON WAVEOFF," and "APC IN USE."

A Refined Version of the Training Format

The initial NCLT data collection software system included a preliminary version of a performance analysis printout. An improved training aid will be developed during the analysis phase. The LSO's input is the key element in this development. The goal of this printout is to assist the LSO in his training task. There are several potential output formats; one possibility is shown in Figure 8.

PILOT:		DATE:	NCLT PERIOD NO.		LSO:
	AVE GRADE	CALL BALL	MIDDLE	IN CLOSE	RAMP
GLIDE SLOPE	3.21	H-L--L--	--HH-L--	H--H--H-	--H---H-
LINE UP	3.32	LR--R--R	-R--R---	-R------	-------L
AOA	2.91	HH--L---	-H--L---	-L-L--LL	H----L--
FUEL FLOW	3.16	L--H--LL	-L----LL	HL-LH--L	H--H---H
PITCH	2.80	HH-LL---	-HLLL---	-L----LL	-H---L--
PASSES 1 THRU 8					
				PASS	12345678
				WIRE	33433341
				LSO GRADE	33234332
				MEAN LSO GRADE	2.80
				MEAN CALC GRADE	2.65
SUMMARY COMMENTS BY LSO					

Figure 8. Period Trend Analysis Summary

This printout summarizes an entire NCLT period. Each column under each segment of the approach corresponds to a separate pass. In the example, the first pass was high on the glideslope, the second pass was on the glideslope, the third pass was low, etc. The wire number and LSO grade are summarized in the block at the lower right. It can be seen that significant trends would readily show up in this summary. Coordination with the LSO will further define the most desirable summary format.

Current NCLT trend analysis comments flag positional and range parameters that stray from nominal values. LSO's have mentioned that the decelerating pass never gets identified, nor is a good correction ever recognized in the data output. Pilot responsiveness (acting upon or ignoring) to a LSO command is also not considered. Several LSO's and pilots have mentioned the desirability of giving the pilot credit for exceptional performance. The LSO will do this occasionally with comments such as 'good correction' or 'rails pass'. An attempt will be made to explore the possibility of making similar note of outstanding performance in the NCLT. It is felt that the collection of both LSO comment data and objective performance data offers a unique opportunity with which to explore this relatively untouched region of performance evaluation.

For example, if beyond a certain minimum range, a pilot can correct an excessive (but not dangerous) positional error and maintain the optimum flight path for the remainder of the pass, such a complimentary comment could be made. If implemented, the feature could prove to be a strong motivator for the pilot in the simulator.

In addition to the automatic comments featured in the current training aid printout, dangerous performance tendencies or 'NO-NOs' will be investigated. In conjunction with this, several LSO's have mentioned that it may be desirable to call greater attention to the existance of such unacceptable performance. This could be done by printing a large 'X' through the output. In order to better distinguish performance that is just outside acceptable boundaries, LSO's indicate 'slightly high', 'slightly low', 'slightly fast', etc. The LSO currently notes this with parentheses, i.e. (HIGH) means slightly high. The same scheme will be considered for the automatic trend analysis printout.

Preliminary Analysis of a Sample of Replacement Pilots

This is a quick analysis of NCLT data for twenty-three replacement pilots. The sample is a mix of RP's who subsequently reported for CARQUAL aboard either the USS Saratoga during the period 10-11 May 1975, or the USS Kitty Hawk during the period 2-8 February 1976.

Of the total sample of twenty-three RP's, three failed to qualify during night CARQUALS. This situation offered an opportunity to test for the predictive capability

of NCLT performance and system credibility. Two other pilots failed to qualify during these CARQUALS. However, sufficient NCLT data for these two pilots were not available for inclusion in this analysis.

Figure 9 compares mean NCLT lineup error data for the three RP's who failed during CARQUAL with the samples of 20 RP's who did qualify. For reference, values for the total sample are shown as a dashed line. Percentage

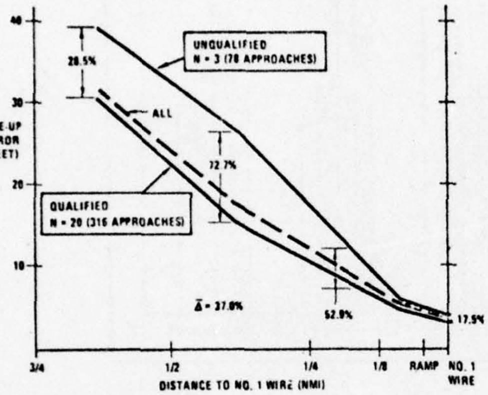

Figure 9. Mean Lineup Error - Qualified Versus Unqualified Groups

differences between those who qualified and those who did not are shown at the midpoint of each segment. The differences are rather startling.

Figure 10 is a similar comparison for mean glideslope error.

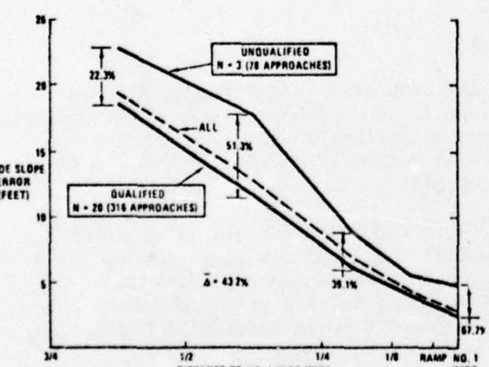

Figure 10. Mean Glideslope Error - Qualified Versus Unqualified Groups

These figures show that the three unqualified individuals performed far worse than the class average in both lineup and glideslope control. The percent differences (Δ) values between the two groups are shown at five points. The overall $\bar{\Delta}$ is shown in the box in the lower center of the figures. It should be noted that the data plotted reflects arrested landings only. Waveoff and bolter rates for the three unqualified individuals were also significantly higher than the class average.

Figure 11 compares qualified and unqualified group performance grades for lineup, glideslope, fuel flow, angle of attack and pitch attitude. This comparison shows that the unqualified group was graded lower in lineup, glideslope, and fuel flow, but higher

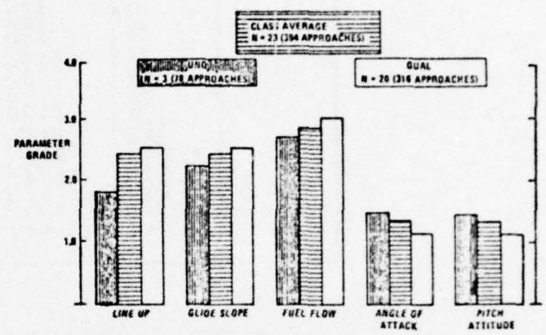

Figure 11. Parameter Grades - Qualified Versus Unqualified Groups

in angle of attack and pitch attitude. This could be an indication that the unqualified group tended to emphasize control of these parameters at the cost of control in the others (i.e., cockpit instrument scan versus position cues). The lineup and fuel flow deltas appear to be about right, but the glideslope grades are closer than the preliminary data warrants. This indicates that the glideslope grading equation may need to be more reflective of "close in" error.

Figure 12 compares a student who was disqualified during NCLT and FCLP with another student who was killed as a result of a ramp strike and with the two samples of students who either qualified or were disqualified at the ship. It should be noted that in all cases of disqualification, the students were graded lower in lineup, glideslope, and fuel flow but higher in angle of attack and pitch attitude. This indicates more emphasis by the student on certain parameters.

The foregoing data indicated a strong predictive relationship between NCLT performance and night CARQUAL performance, even though the preliminary analyses to date represent only rudimentary efforts.

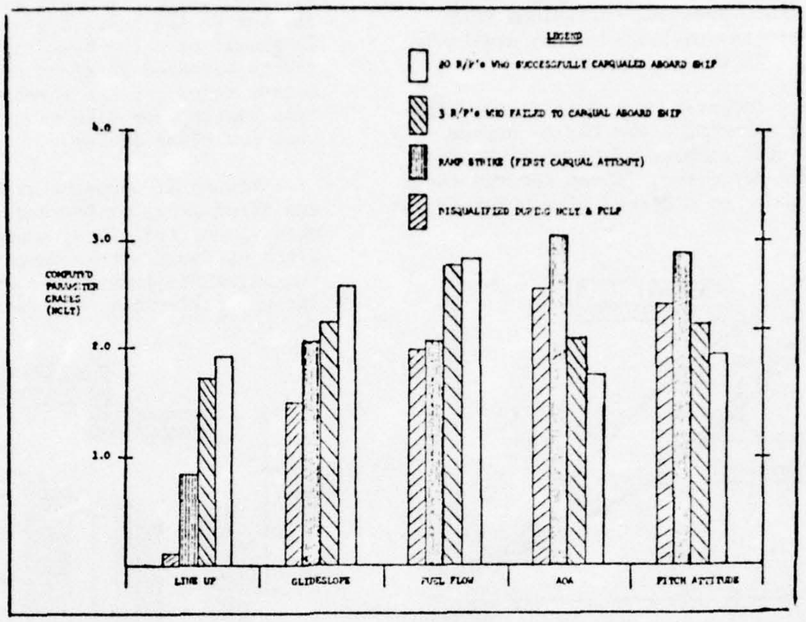

Figure 12. Comparison of Computed Parameter Grades

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TRAINING USING INTERACTIVE COMPUTER GRAPHICS FOR SIMULATION

ALICE M. CRAWFORD and RICHARD E. HURLOCK
Navy Personnel Research and Development Center[1]

Conventional military training of performance-oriented skills generally requires that students study concepts in an individualized learning module and then practice on actual equipment or a high-fidelity simulator. Not only are these training programs costly, but considerable research has shown that, for certain skills, such hands-on practice with operational equipment may not be necessary for adequate transfer of training (Hageman and Stockton, 1975).

Rather than high-fidelity appearance, the critical component in determining the effectiveness of a training device may be the degree to which students are allowed to practice behaviors crucial to performance in the operational situation (Analysis of the Transfer of Training, Substitution, and Fidelity of Simulation of Training Equipment, 1972). Thus, researchers are beginning to focus more attention on the underlying principles of learning as opposed to concentrating on creating exact replications of the actual equipment.

Consistent with this trend, the present researchers were interested in developing and evaluating a training methodology which combined low-fidelity appearance simulations with established principles of instruction.[2] Specifically, interactive graphic simulations presented on a computer-based training (CBT) instructional system were investigated with respect to their potential for effective low-cost training.

As compared to conventional methodologies, interactive computer graphic simulations could offer the following advantages:

a. Simulations presented on a CBT system may be combined with instructional text and automatic performance recordings for feedback and later evaluation.

b. A CBT system used as a training device offers a tremendous amount of flexibility in that simulations may be programmed within the framework of any learning strategy or content sequencing algorithm.

c. The CBT terminal would have a general-purpose simulation capability in that the various operations on different pieces of equipment could be simulated by simply accessing different lesson software.

Lahey, Crawford, and Hurlock (1975) and Stern (1975) provided initial evidence indicating the potential effectiveness of interactive computer graphic simulations for training. In both studies computer graphics were used to dynamically simulate equipment operations. Students were able to interact with these simulations as they would with the actual equipment. The present effort was designed to be a more comprehensive test and evaluation of the operational and technical feasibility of this methodology. More complex simulations were programmed and more distinctly performance-oriented skills were taught than in the previous studies. It was felt that, if effective and low-cost training was demonstrated in this study, the data would serve as an approximation toward making generalizations for using similar applications to reduce military training costs.

THE COMPUTER-BASED TRAINING PROGRAM

PLATO IV

CBT materials were programmed and run on the PLATO IV (for Programmed Logics for Automated Teaching Operation) Instructional System which is driven by a CDC Cyber 73 computer. Data is transmitted between the computer and remote student terminals by voice grade telephone lines. Each terminal had a 64-character keyboard, an 8½-inch square plasma display panel, and touch panels which enabled the students to enter data into the computer when they pointed at any of the 256 programmable areas of the plasma panel. The touch panel consists of a thin framework which is substituted for the normal metal front frame of the PLATO IV terminal. The

[1]The opinions and assertions contained herein are those of the writers and are not to be construed as official or as reflecting the views of the Navy Department, Naval Service, or Department of Defense.

[2]This project was jointly sponsored by the Joint Services Training Technology Program of the Defense Advanced Research Projects Agency.

panel contains the necessary electronics (scanning system, infrared light emitters and detectors, control logic, and cable to connect with the terminal connector) to permit the panel to operate as an auxiliary input device. The light emitters and detectors are evenly spaced in a 16 by 16 array. The invisible paths formed by the light rays across the exterior surface of the plasma panel describe a checkerboard-like array of 256½-inch square points which may be selected by the student. Inputs are sensed by the system when the beams of light emitting from the X and Y aces are broken simultaneously by the student's pointing responses. Input rate is limited by the touch panel circuitry to about 10 selections per second. Further information on the system is provided by Stifle (1972a, 1972b, 1973).

Training Materials

CBT materials developed consisted of interactive computer graphic simulations of the front panel topography and all operations of the S-3A Copilot Integrated Control System (INCOS) Panel Multipurpose Display (MPD). The INCOS panel is used for communications between the on-board computer and the operator for the utilization of nonacoustic sensors and computerized navigation. Operator interactions with the panel are reflected in changes in tactical symbology and tableaus, readouts, and alerts as seen on the MPD. Procedural and simple perceptual motor skills are required to operate the INCOS panel.

The computer-based simulations were accompanied by instructional text, guided practices, extensive feedback and test sequences designed to teach the copilot the operations of each panel component. All materials were intended to elicit maximum participation on the part of the student.

The PLATO IV touch panel was used to present CBT materials in a manner which would permit students to respond to stimuli from the simulated panel simular to the way they would in the operational situation. Displays were created by interactive computer and graphics in which the students could touch simulated panel components and produce responses from the panel and/or modifications in the display on the MPD. The plasma panel displayed clear, graphic, and close to actual size, simulations of the INCOS panel, and was able to produce all of the same visual effects which are present in the S-3A.

The training materials were presented in the framework of a learner-controlled lesson which included behavioral objectives, examples, guided practices and diagnostic tests.

A data collection system was programmed in conjunction with the training materials to record the following data:

a. A trail of students' progression through the lesson and each response made.

b. Measures of time spent in each practice segment.

c. Correct and incorrect responses made to each test item.

Procedure

Two groups of S-3A copilots from the Fleet Avaition Specialized Operational Training Group Pacific Fleet (FASOTRAGRUPAC) were used as subjects to test the effectiveness of the computer-based simulation methodology. The first group studied INCOS operations using PLATO IV CBT materials. The second underwent conventional FASOTRAGRUPAC training; that is, subjects spent 8 hours, studying a workbook, which described each of the panel components in conjunction with sequential pictures of panel and display actions and provided test questions. Training times were determined by time required to complete the materials. Overall training objectives were similar for both forms of training.

Following training, both groups were administered two performance posttests--one before and one after a 1-hour practice session in a high fidelity simulation position trainer (PT) of the S-3A copilot seat. Repeated measures (test performance before and after the practice session) were obtained for all subjects. During this practice session, which is a standard scheduled portion of FASOTRAGRUPAC INCOS training, the instructor guides the student through a series of exercises.

Each test required the student to perform two tasks using the INCOS panel. Each task was in the form of a request for a terminal behavior and required from 6 to 10 sequential responses. A maximum of 3 minutes was allotted for successful achievement of each task. During both posttests, an experimenter sat next to the student to maintain a checklist of the sequence of student responses made on each task and to record the time required.

Results

The dependent measures used for data analysis were the number of tasks completed (0, 1, or 2) in each test, and the time required to complete each test (the maximum possible was 6 minutes).

Two-way (groups by form of test administered) analyses of variance were performed on all data to compare the performance of: (1) CBT students versus workbook students on Test 1, (2) CBT students versus workbook students on Test 2, and (3) CBT students on Test 1 versus that of workbook students on Test 2. Table 1 presents the mean score for both groups on the two dependent measures.

On the performance test given immediately after training, analysis of the data revealed that CBT students completed more problems ($F = 9.92$, $df = 1/40$, $p < .005$), and finished more quickly ($F = 23.29$, $df = 1/40$, $p < .001$) than did workbook students.

After a 1-hour practice session in the PT, CBT students were still performing better than workbook students. Their performance scores for Test 2 showed that, again, they completed more problems ($F = 5.29$, $df = 1/40$, $p < .05$), and their tests were completed in less time ($F = 16.68$, $df = 1/40$, $p < .001$).

A final analysis was performed on data obtained from CBT students on Test 1 and workbook students on Test 2. This comparison revealed no significant differences between scores of the workbook students who had had hands-on experience in the PT and those of the CBT students who had not yet practiced with the actual equipment.

Data were also collected from the instructors at FASOTRAGRUPAC. Given that these men have had extensive experience with the INCOS system, it was felt that their scores would reflect a realistic estimate of the minimum time for the performance on both forms of the test. Instructor and student time data is shown in Table 2.

An incidental finding was that after 3 hours of training on PLATO IV, and following the performance tests in the PT, 68% of the experimental students returned to study the PLATO INCOS lesson (on their own time) for 1.5 to 3.7 additional hours. Average total time on the system for all CBT students was 4.8 hours.

TABLE 1. COMPARISON OF GROUP PERFORMANCE ON TESTS 1 AND 2

Group	Test 1 Time (Min.)	Test 1 No. Tasks Completed	Test 2 Time (Min.)	Test 2 No. Tasks Completed
Computer-Based Training	2.85	1.68	1.88	2.00
Workbook	4.44	1.18	3.32	1.73

TABLE 2. MEAN TIMES TO COMPLETE PERFORMANCE TESTS FOR INSTRUCTORS AND TRAINEES (In Minutes)

Test	Instructors Mean	Instructors SD	Computer-Based Training Group Mean	Computer-Based Training Group SD	Workbook Group Mean	Workbook Group SD
1	.63	.14	2.85	1.20	4.44	1.30
2	.67	.21	1.87	.84	3.32	1.49

EVALUATION

Training Effectiveness

Results of analysis of the data collected from both dependent measures clearly indicated that the CBT with interactive graphics provided training which was superior to that provided by the conventional program. The findings suggest that CBT materials can be used operationally either to supplement or replace conventional training programs.

The present data support the possibility that supplementation of a conventional training program with computer-based simulations might permit students to obtain maximum benefits from experience with the operational equipment. While both control and experimental groups showed improved performance following the PT exercises, CBT students performed significantly better than the control group. Given that hands-on experience with the operational equipment did not bring all students to the same-level of mastery, as indicated by instructor data, it is reasonable to conclude that CBT plus hands-on experience with actual equipment provided the best training.

While supplementing a conventional program with a computer-based simulation of operational equipment may be beneficial in some situations, eliminating the conventional program in favor of the computer-based simulation may, under some circumstances, provide the most efficient training. This could prove to be the case with the S-3A INCOS training program. An important finding of the research was that CBT students performed required behaviors in the PT as well before the practice exercises as conventionally trained students did after the exercises. Because the S-3A staff has always considered conventional student proficiency level following PT exercises acceptable, the findings of this research imply that CBT could be used to replace the PT during this phase of copilot training.

The fact that performance was not degraded by the absence of conventional hands-on practice has important implications for training. It appears that computer-based graphic simulations may be an appropriate methodology for teaching various levels of performance-oriented skills. Precise specification of these levels will be investigated by further research. It is not clear, however, whether a less expensive media, such as slides, would have produced equally effective training. It does seem possible that higher level skills may be effectively taught using computer-based simulations.

The materials developed for the INCOS simulation may be easily converted for use in other phases of copilot training or for training other S-3A operators. Thus, it is advantageous to attempt to isolate the specific variables responsible for the success with this methodology.

Cost Benefits

Costs associated with delivering computer-based training with a PLATO IV system are a function of the number of hours the terminals are used per year, and whether they are purchased or leased. Figuring by the least expensive way, that is, assuming that terminals are purchased with their cost amortized over 10 years and they receive maximum utilization, the cost per student contact hour is about $5.00, including time-sharing expenses. Thus, since each student in this study had 3 hours of PLATO training, CBT was delivered at a cost of $15.00 per student.

The cost of the conventional training this could replace may be conservatively estimated at $118.00. This figure is based on amortization of the costs of the position trainer and its maximum utilization.

The implications of the cost figures are that $20,000.00 per year, or almost a quarter million dollars over a 10-year period, could be saved. Additional savings include 5 student hours and 1 instructor hour for each man trained, and the time saved on the PT which may then be used in more advanced training situations.

CONCLUSIONS

The present study has demonstrated the usefulness of CBT with interactive graphic simulations for part-task training of certain performance-oriented skills. Using this methodology to supplement or replace some conventional training programs which use actual equipment or high fidelity simulators for hands-on training appears to be technically and operationally feasible. Graphic simulations have numerous capabilities which are advantageous for training as compared to the conventional programs. CBT systems can combine simulations of operational equipment with any instructional strategy, feedback, recording of student performance data, and instructional sequencing.

The PLATO IV instructional system was demonstrated to be a good vehicle for presenting interactive training materials.

Cost figures show that, with full terminal utilization, PLATO IV can provide cost-effective training as compared to the conventional training. The system also offers considerable potential as a general-purpose training device. Different pieces of equipment may be simultaneously simulated at different terminals or a piece of simulated equipment may be updated by simply accessing different lesson software.

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MAXIMIZING FLIGHT FIDELITY;
INTEGRATION OF NAVAL AIR TEST CENTER CAPABILITIES
INTO THE PROCUREMENT OF MAJOR AVIATION TRAINING DEVICES

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Flight test engineers and test pilots from the Naval Air Test Center (NATC) have recently become involved with evaluating the flight fidelity of new Operational Flight Trainers (OFT) and Weapon Systems Trainers (WST) being procured by the U. S. Navy and Marine Corps. The purpose of all NATC flight fidelity evaluations is to answer the question: Does this Device fly like the airplane? To formulate such an answer, these engineers and test pilots compare OFT/WST simulated flying qualities, performance, engine systems, and weapons/avionics systems characteristics to those of the actual airplane. The major component of NATC testing is the application of quantitative test techniques to identify fidelity deficiencies and eliminate dependence on purely subjective analysis. The quantitative test techniques applied here are generally identical to those routinely utilized by NATC during aircraft flight test programs. The extent of NATC involvement in OFT/WST testing is outlined in table 1.

NATC Test Background

The type of airplane testing conducted by NATC is definitely germane to simulator fidelity testing. In brief, the mission areas of NATC that are relevant to OFT/WST fidelity include testing of aircraft flying qualities, performance, carrier suitability, propulsion systems, and mission systems (avionics, ECM, radar, reconnaissance sensors) for all Navy and Marine Corps fixed wing, rotary wing, and VSTOL aircraft. The normal NATC cycle begins with Navy Preliminary Evaluations (NPE) conducted at the contractor's facility at various stages of the aircraft and system development. The purpose of these NPE's is to discover serious deficiencies early enough to allow correction by the contractor without delay in delivery to the fleet. The guidelines for such testing are contained in the demonstration specification, MIL-D-8708, which calls for five NPE phases with the first phase occurring within 90 days after the first flight of the new aircraft. After the NPE phases of testing are complete, fleet representative aircraft are evaluated at NATC with contractor demonstrations of contract guarantee items and Navy Board of Inspection and Survey (BIS) service acceptance trials. Finally, a follow-on technical evaluation is usually conducted at NATC to document pertinent characteristics. Such a test process usually results in large quantities of data at NATC concerning airplane and system characteristics. Unfortunately, time and money constraints generally limit published data to documentation of deficiencies and flight characteristics at the edges of the flight envelope. As a result, the mid-envelope characteristics needed to assess OFT/WST flight fidelity remain undocumented and further flight tests are required. Data availability and flight test requirements are discussed in depth in later paragraphs.

OFT/WST Test Policy

The initial role of NATC in OFT/WST testing was only to provide airplane data in areas otherwise unavailable to the simulator contractor. It soon became apparent that NATC airplane test techniques were as useful for quantifying OFT/WST deficiencies as they were in the airplane. Unfortunately, these initial efforts by NATC occurred during final acceptance phases of each OFT/WST and considerable delays were incurred since extensive software changes were usually required by the contractor to correct the flight fidelity deficiencies. For instance, in-plant acceptance of the T-2C OFT (Device 2F101) was delayed by approximately six months primarily for flight fidelity problems and the A-4M OFT (Device 2F108) in-plant acceptance was similarly delayed by four months. In order to eliminate these costly delays, NATC simulator project personnel conferred with representatives of the Naval Training Equipment Center (NTEC) and the Naval Air Systems Command (NAVAIR) to develop the most effective means of incorporating NATC into the procurement

TABLE 1. NATC OFT/WST TEST EXPERIENCE

Device	Test Scope	Test Period
T-2C OFT (2F101)	Acceptance testing (Units 1-7)	1973-1975
TA-4J OFT (2F90)	Fidelity improvement for use with visual system	1974-1975
S-3A WST (2F92)	a. Acceptance testing (Units 1 and 2) b. VITAL III retrofit and WST aero update (Unit 2) c. Acceptance testing (Units 3 - 5)	1974-1975 1975-1976 1976-1977
F-14A OFT (2F95)	Aero updates plus retrofit of VITAL II visual evaluation (Units 2, 3, 4)	1974-1976
A-7E NCLT (2F103)	a. Fidelity evaluation b. Aero update evaluation	1974 1976
A-7E WST (2F111)	a. NPE (Unit 1) b. Acceptance testing (Units 1 and 2)	1975 1975-1976
A-4M OFT (2F108)	Acceptance testing (Units 1 and 2)	1975-1976
KC-130F OFT (2F107)	Acceptance testing	1975-1976
SH-2F WST (2F106)	a. Acceptance testing (Units 1 and 2) b. VITAL III visual retrofit	1975-1976 1976
F-4J WST (2F88)	Acceptance testing (USMC)	1976
EA-6B WST (2F119)	a. Proposal evaluation b. Monitor development, base-line data generation c. Testing (NPE, Acceptance)	1975 1976 1977-1978
A-6E WST (2F114)	a. Detail specification comment b. Baseline data generation c. Acceptance testing (Units 1 and 2)	1974 1976-1977 1977-1978
FUTURE PROGRAMS: E-2C OFT (2F110) F-14A WST (2F112) CH-47E OFT (2F117) ACMT (2E6)	a. Monitor development b. Testing (NPE, Acceptance)	1976- 1977-

cycle of new OFT's and WST's so that flight fidelity would be assured and realistic development and testing schedules could be written. The major elements of the Navy test policy so developed are outlined below. It should be noted that the NATC OFT/WST project engineer/test pilot team participates only in as many of the tasks as required by NAVAIR. The major elements are:

a. Establish liaison with appropriate NAVAIR and NTEC personnel.

b. Assist in specification preparation, proposal evaluation, and monitor the contractor's development effort, where possible, to assure flight fidelity.

c. Provide NATC-developed flight test data as needed for OFT/WST development and as standard for measurement of flight fidelity.

d. Conduct Navy Preliminary Evaluations (NPE's) of the OFT/WST during development.

e. Participate in in-plant acceptance testing.

f. Provide engineering and test pilot assistance in adjusting hardware and software to achieve proper flight fidelity.

g. Participate in on-site acceptance to validate OFT/WST flight fidelity.

h. Participate in validation of subsequent OFT/WST units during in-plant and on-site acceptance.

i. Conduct follow-on evaluations of update (ECP) efforts affecting flight fidelity.

j. Prepare reports documenting flight fidelity of the OFT/WST.

The major innovations to the OFT/WST procurement process are items c. and d. from the above list. The advantage of incorporating NATC-developed flight test data as early as possible to describe the characteristics to be simulated is obvious. The introduction of the NPE concept to simulator flight fidelity testing is a direct adaptation of U. S. Navy aircraft procurement policy. The advantage of early deficiency detection through brief evaluations of the OFT/WST during the development phase is that more time is available to the contractor to develop improvements by obtaining more data and to refine the hardware and software. To date, the only simulator we have been able to evaluate under the NPE concept was the A-7E WST, Device 2F111, in January 1975, where NATC conducted a four-day period of tests of flying qualities and performance. This evaluation was possible only because of a gap in the development process (the radar simulation equipment was not ready) but it did reveal some problem areas in time to obtain appropriate data for clarification of these problems before acceptance testing began. For the future, similar NPE efforts are planned for the E-2C OFT (Device 2F110) and EA-6B WST (Device 2F119). The number of NPE's required for any particular OFT/WST will vary with the complexity of the simulator (OFT vs. WST) and the development progress (readiness of avionics, motion system, etc.). Regardless of the number of NPE's, each NPE is intended to be a three to five-day evaluation on a frozen-configuration at significant milestones during the development phase.

OFT/WST TEST EXPERIENCE

Baseline Data Accumulation

Regardless of what point we enter the OFT/WST development cycle, the NATC project team always begins baseline data accumulation by searching out appropriate published and unpublished flight test data. If the airplane being simulated is still being tested in the normal NATC test cycle, then usually a wealth of useful but unpublished data is available. This was the case during acceptance testing of the S-3A WST and and the F-14A OFT. However, the approach of "piggy-backing" OFT/WST test requirements with airplane development testing produces only limited results since data requirements may differ and airplane program requirements take priority over simulator requirements in competing for expensive flight time in a fully instrumented airplane.

For most of our OFT/WST programs, insufficient data exist so that additional flight tests are required to build the required data base, and this is generally done with uninstrumented fleet airplanes. However,

data gathering in fleet aircraft holds several advantages in that the fleet airplane is usually more representative of the simulator configuration than the test articles at NATC. In addition, testing of several fleet airplanes allows documentation of average airplane characteristics, particularly with respect to control system characteristics. Normally, about 15 hours of flight time are required to build an adequate data base, and tests conducted include documentation of mid-envelope airframe and engine characteristics, response to small inputs in all axes, and open loop characteristics at high angles of attack or during configuration changes. Use of relatively simple instrumentation such as hand-held force gauges, stop watches, tape measures, and production cockpit instruments, has proven to be adequate and allows considerable flexibility in going from one cockpit to another, be it airplane or simulator. The use of such austere instrumentation also permits rapid data generation in the airplane should significant gaps or questionable areas arise during simulator testing. Also, the use of identical instrumentation in the airplane and simulator enhance the repeatability of test techniques and data.

We do not, however, consider the extensive use of hand-held instrumentation a panacea. If additional meaningful test data from an instrumented airplane becomes available during a simulator test period, we do not hesitate to use it. Of course, it would be far more desirable if such data were available in advance so that a contractor could detect a fidelity problem before Navy testing commences. The effort is underway within the Navy to apprise aircraft program managers of simulator data requirements so that funding is available to publish all pertinent data and so that aircraft test programs can include maneuvers for simulator needs along with the usual airplane specification test requirements. Hopefully, this effort will lead to more complete documentation of airplane characteristics in time to aid a simulator contractor during his development phase.

Simulator Testing

Flight fidelity tests on an OFT/WST are conducted merely by repeating airplane test techniques at the baseline data test conditions. It is not desirable for the NATC tests to adhere to some prearranged detailed outline of tests, such as the Acceptance Test Procedures Report, since the test techniques utilized by a test pilot cannot always be described adequately in a step-by-step manner to enable a layman to obtain repeatable results. It is preferable that flying qualities tests such as required to assess maneuvering longitudinal stability be left to a trained test pilot. In addition, fidelity problems may require that a majority of the NATC testing be concentrated in one area, such as lateral control sensitivity, where additional airplane flight tests might be required for data and the test conditions would not be defined to an exact gross weight or airspeed until that time. For this reason, a general outline of the tests to be conducted and the flight envelope to be investigated is considered the most meaningful planning document that NATC can provide a simulator contractor in anticipation of our flight fidelity testing, and we have provided such an outline prior to testing when requested.

The bulk of NATC simulator testing is conducted on the fixed-base cockpit without motion or visual cues since the primary flight fidelity goal is to have the airplane response as seen on the simulator cockpit instruments and controls match the response as seen on the airplane cockpit instruments and controls. Obviously, the OFT/WST flight dynamics (hardware and software) must match on this basis before a meaningful evaluation of the motion and visual cues can be conducted.

Another facet of flight fidelity testing is pilot "memory." During our evaluations, we have found that it doesn't take a test pilot in the simulator very long to forget subtle airplane characteristics. For instance, during tests of the S-3A WST with the VITAL III visual system, an experienced NATC S-3A test pilot became adapted to the simulation within only 30 minutes; that is, during his first 30 minutes of flying landing approaches in the WST, he used normal airplane pilot technique and he encountered extreme difficulty in making smooth approaches. Thereafter, he learned to compensate for the fidelity problems, his approaches became smooth, and his qualitative analyses of the simulation lost considerable

value. The only way to alleviate such a problem is for the pilot to periodically fly the airplane during the OFT/WST test program especially since there are still many subtle flight characteristics, such as closed-loop flying qualities in the approach, which elude quantification and can only be defined properly by refreshed pilot opinion. This practice of pilot refamiliarization was utilized by the NATC test teams particularly during the extensive evaluations conducted on the T-2C OFT and the TA-4J OFT where considerable flight time was graciously provided by the Naval Air Training Command.

Deficiency Resolution

When the NATC test team encounters a flight fidelity deficiency during acceptance testing, the problem is described with as much data as possible in the deficiency report. The intention is to describe the problem well enough to permit the contractor to develop corrections without the presence of the NATC test team. The workload of the NATC test pilots and engineers always includes other projects with varying priority requirements so that extensive tweaking periods at the simulator are a luxury in which we cannot indulge. Therefore, the NATC OFT/WST test team endeavors to assist the contractor as much as possible in isolating a flight fidelity problem, but it must be recognized that presence of the NATC test team at the simulator is of necessity limited to relatively short intervals.

Typical Fidelity Problem Areas

The type of testing provided by NATC can be illustrated by discussing typical fidelity problem areas encountered in our OFT/WST testing. One of the most critical problem areas we have encountered is in control loading fidelity where control stick breakout forces, damping, and centering characteristics are found to be unrepresentative of the airplane. Many times this is due to the use of control system design data vice actual airplane test data, and once the correct data are made available, only simple adjustments are necessary. However, some control loading designs, particularly the electo-hydraulic type, seem to require extensive care to retain alignment which is undesirable from a maintenance standpoint. Obviously, poor control loading fidelity can seriously degrade an otherwise excellent flight dynamics software model.

The flight dynamics software model suffers in fidelity from dependence on wind tunnel data, as everyone knows. Therefore, the NATC test team devotes considerable attention to areas such as the high angle of attack regime since baseline data are usually sketchy but NATC test pilots have extensive flight test experience in this regime. In most cases, a representative simulation of airplane stall characteristics, including motion base buffet cues, can be developed by an experienced test pilot working in conjunction with contractor software experts. In addition, many flight fidelity problems are compounded by software short cuts such as low computation rates to save computer time and delayed output of computed variables such as roll angle to the pilot's gyro. Admittedly, software architecture is out of the NATC realm of expertise but these problems are mentioned only because we can recognize their effects on fidelity when trying to assist the contractor in identifying the source of a flight fidelity problem. Finally, the refinement of visual scene response has always proven to be difficult, especially for closed-loop tasks such as landing approaches. Some success has been achieved, particularly with the TA-4J OFT at NAS Kingsville and the S-3A WST/VITAL III at NAS Cecil Field, by careful adjustment of appropriate software terms while repeating a well defined task until a representative simulation is achieved.

Simulator Certification

As the dependence on OFT's and WST's increases in maintaining pilot proficiency in the U. S. Navy, so will the demand that adequate fidelity be developed and retained in these simulators. Any future simulator certification programs should definitely include flight fidelity evaluations by NATC test pilots and engineers. Such evaluations would be similar to the brief on-site validation tests currently conducted when a new device is first installed, but they would serve to confirm adequate fidelity or help define any new problem areas which might have crept in due to control loading degradation or inadvertent software changes. Our experience with the TA-4J OFT and the S-3A WST showed that these problems do occur. Therefore, the use of quantitative testing by an NATC project team, particularly in flying qualities evaluations, is

just as necessary for certification as in acceptance testing.

CONCLUSION

In summary, the utilization of NATC flight test data and quantitative test techniques in OFT/WST flight fidelity evaluations has increased steadily since 1973. An orderly process for including NATC inputs into the OFT/WST procurement process as early as possible has been developed in conjunction with the Naval Air Systems Command and the Naval Training Equipment Center. An effort is underway to include simulator data requirements with existing aircraft testing requirements for future airplane and OFT/WST procurements. Current NATC flight fidelity test programs have shown that meaningful data can be obtained with simple hand-held instrumentation, that the test pilot must frequently refamiliarize himself with subtle airplane characteristics during the simulator evaluation period, and that NATC evaluation periods are best conducted over brief periods beginning sometime in the development phase. Hopefully, such extensive efforts to achieve maximum flight fidelity will increase the training value of OFT's and WST's, or at least make the use of such devices more palatable to Naval aviators than in the past.

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PERFORMANCE ORIENTED AIRCREW TRAINING: OPTIMIZATION THROUGH ISD*

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Traditionally, training programs within the military have been generated in-house by a number of instructor personnel tasked with the difficult problem of sorting through all available information and developing an approach to the classroom presentation of an assigned content area. The resulting instructor guides (outlines) and student handouts are, by necessity, based on information within each individual's realm of experience. This experience is largely based on prior instruction and specialized operational missions. Of particular significance in such an approach to training is a failure to conceptualize the entire system in perspective. This results in a piecemeal, poorly-coordinated buildup of instructional units with retrofitting as the method of necessity for curriculum development. Furthermore, the Subject Matter Experts (SMEs) approaching the task usually do not have the benefit of expertise in the principles and application of instructional technology. The problem is complicated by the rapid turnover in instructor personnel. Often too, an attempt is made to piece together the in-house training materials, typically instructor guides (outlines), with separately developed technical materials provided by a contractor to complement existing hardware. The classroom instructor is ultimately left with the task of integrating the curriculum while performing within the confines of the existing policy and procedure of the training command.

With the limited resources and increased demands which are placed upon the military training community today, the advent of a technology of instructional systems development has demanded more attention than it might have in more affluent times. The challenge for greater efficiencies in the learning process and greater cost-effectiveness in the training program has been recognized by the R&D community and has resulted in the derivation of numerous instructional models. Most of these models, which are generally oriented toward individualized instruction, have been based upon a process leading from task analysis and behavioral objectives to curriculum development and evaluation. While these models are continually undergoing refinements, the need is pressing for the implementation and concurrent evaluation of the basic conceptual framework of the Systems Approach to Training (SAT) within the operational training community. One such effort, which has been initiated within the Navy's E-2C aircrew training program, will be briefly described in this paper.

APPROACH

The Calspan Human Factors Section has approached the problem of developing an E-2C SAT program (Sugarman, et al,1976) by coordinating the skills and experiences of specialists in the disciplines of psychology, education, human factors engineering, and aviation. Each of these specialists was selected for the effort on the basis of prior operational and/or training experience with military aircraft. In addition, one Calspan analyst (a pilot/navigation-rated engineer) received additional subject matter expertise through participation in an NFO transition course. The general Calspan approach to SAT programs is to put together such a team which is first and foremost a group of experts in SAT technology, but whose familiarity with the subject matter is significant so that:

a. high rapport can be established with the users;

b. subtleties of the mission requirements are not overlooked;

c. operational policy and constraints can be fully appreciated;

d. total reliance is not placed on the availability or cooperation of the user's subject matter experts; and,

e. full advantage can be taken of the SAT analysts' familiarity with other relevant missions and training operations.

The combination of this type of SAT analysts, who know the questions, with an ample supply of user experts, who know the answers, ensures the highest quality possible for the results of such efforts.

The development of a comprehensive data base was the first task in applying the Calspan SAT methodology to the E-2C training program. This was accomplished through a two-faceted analysis. One facet involved an extensive analysis of the existing training

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program. The second facet consisted of a task analysis (Mitchell, 1975a; Hinton, 1975a). The background information for the NFO task analysis was established through firsthand observation and recording of classroom presentations conducted by squadron training personnel. While this appeared to be the most efficient in terms of obtaining information about the NFO/FT training, Calspan's previous experience with the pilot/co-pilot training task and the availability of documentation (including recently developed audio-visual presentations) for a significant portion of that training, alleviated the necessity for a corresponding approach. In both cases, however, all available training documentation was collected for analysis.

These informational sources were then supplemented by informal interviews with squadron training personnel and direct observations of operational equipment/simulators and crews. In this procedure, heavy reliance was made on two sources, subject matter expertise and operational documentation. These sources, together with classroom lecture notes covering operational information not otherwise available, provided Calspan with the basic information for preparing the task analysis listing.

The format which was employed for the task analysis was one adopted from experience with a previous training program design. The resulting data base consisted of a detailed hierarchical breakdown of all activities required to perform the mission. Of special significance were the level of detail (task element level), the mission-performance/system-operation orientation, and the display-operator-control relationships. Furthermore, an additional effort was made to include remarks pertinent to task performance but not directly reflected in the action statement. Much attention was given to this effort, as it was designed to provide the information necessary to formulate behavioral objectives and to provide the structure of the lesson specifications later in the program.

The next step involved the identification of training objectives. This was basically a two-stage process. First, the task analysis was partitioned into a listing of discrete behavioral components that formulated the behavioral objectives (Mitchell, 1975b; Hinton, 1975b). Included in the objectives were key features such as ratings of performance criticality and difficulty, and the specification of performance limits. The second stage involved the "subtraction" of the incoming skills and knowledges. These incoming skills and knowledges for various trainees were established through discussions with squadron personnel as well as an analysis of documents related to their previous training. Thus, the behavioral objectives minus the incoming skills and knowledges resulted in the listing of actual training objectives. These, too, were later used in the preparation of lesson specifications as the key determinants of content areas.

The final task was the preparation of lesson specifications (Fishburne, et al., 1976; Hinton and Blair, 1976). As alluded to earlier, each of the previous steps contributed directly to the product of this effort. The behavioral objectives, operational policy, availability of resources, and incoming skills and knowledges played a key role in the instructional design. The format of the lesson specification was thus divided into three continuous domains-- cognitive, practice, and sortie/scenario. In the cognitive domain, the sequence of instruction was designed to present in a hierarchical manner (building a network of associations upon the developing repertoire) that information which directly contributed to mission performance and/or system operation. Accordingly, the structure of the training objectives was used as the basis for the teaching points in the lesson specifications. The ordering of the objectives was permuted, however, in consonance with learning strategies.

Integral to the preparation of lesson specifications were the media analysis and the determination of instructional strategies and sequences. The specification of training devices was based on the training objectives identified during the SAT process and was oriented toward obtaining the best possible trainee performance at the least possible cost. The sequencing of instructional blocks was based on both learning principles and effective resource (device) utilization. These two efforts are detailed in the paragraphs below.

MEDIA ANALYSIS

Two general principles were followed in determining the training media support requirements for the pilot and NFO/FT training courses. The first principle was to make the maximum possible use of existing media and those currently under procurement. This involved the mapping of training objective media requirements into the available training media capabilities to evaluate how effectively the training objectives identified during the SAT process can be taught using those media. During the mapping process, particular emphasis was placed upon evaluating the hands-on capabilities of the devices.

The second principle involved a tradeoff analysis to determine the need for the procurement of new devices or modifications

to existing devices. Factors considered in this analysis were (1) deficiencies in the current devices as determined by the mapping of media requirements into media capabilities, (2) the cost of procurement of new devices, (3) the demand on existing and new devices as a function of trainee flow rate, and (4) the degree of improvement in training effectiveness to be expected by procuring new devices or modifying existing ones. The degree of improvement expected was based on a consideration of some of the basic principles of learning, e.g., hands-on learning facilitates the acquisition and retention of psychomotor skills; individualized, self-paced instruction enhances cognitive learning; and testing is most effective when it immediately follows instruction to allow timely feedback and remediation.

A comparison of the stimulus characteristics inherent in the available devices with the stimulus characteristics judged by SAT analysts to be essential for the training of procedure-oriented objectives, indicated that the existing training devices as they are currently configured, provide ample capabilities for hands-on learning. The main function of the SAT process with respect to these devices was to ensure their effective utilization as a function of instructional strategies and sequencing.

From the vast plethora of educational research that has been conducted in recent years, three instructional principles, which increase learning speed and enhance retention of academic material, have emerged. These principles involve: (1) student-paced instruction; (2) individualized presentation; and (3) immediate knowledge of results. The use of an individualized, self-paced instructional medium accounts for individual differences in learning time and learning style, and when supplemented with a testing session at the end of each lesson, provides the student and instructor with immediate feedback of student performance. This immediate knowledge of results allows the student to review the content of the lesson for remediation while lesson content and problem areas are still fresh in his mind and also assists the instructor in offering prompt remediation guidance.

The results of this SAT analysis are particularly appropriate for implementation in an individualized training medium. Through the structured steps of a SAT analysis only those teaching points which will impinge upon subsequent trainee performance are selected for instruction. Those selected teaching points are further ordered into a logical sequence of discrete steps which can be readily converted to an individualized instructional format. Thus, through this selection and ordering process the need for student-instructor interaction is minimized in duration, but optimized for utility.

Within an instructional sequence in which the teaching of psychomotor and cognitive skills is integrated (see next section) the implementation of an individualized system for cognitive instruction allows for more efficient use of student time. In such a system the training technique for cognitive skills is consistent with that for psychomotor skills, i.e., both cognitive and psychomotor skills are taught individually. By using an individualized approach to cognitive training, as well as to psychomotor training, there is much more flexibility available for the scheduling of psychomotor lessons, because device utilization times are not determined as a function of times when classroom lectures are scheduled. Rather, the scheduling of training devices can be arranged so as to make the most efficient use of all available resources. For example, with an integrated, totally individualized system one student may be engaged in cognitive training at the same time another student in the same convening class is engaged in psychomotor training in a simulator.

The effectiveness of classroom versus individualized instruction was recently compared for two Navy training courses, the Aviation Familiarization Course (AFAM) and the Aviation Fundamentals Course (AMFU). The results indicated that learning time was 30% to 60% less for the individualized instruction, while immediate and delayed test performance (retention) was essentially the same for the two instructional techniques.

Individualized, self-paced instruction should not be implemented independent of a consideration of the media requirements of each training objective. For example, some objectives are amenable to self-paced individualized instruction, while other objectives can more effectively be taught in a group setting.

On the basis of an evaluation of the subject content of the pilot and NFO/FT cognitive training objectives, SAT analysts determined that an individualized, self-paced instructional medium should replace the traditional classroom lecture as the preferred medium for cognitive instruction. To supplement this medium, classroom lecture/discussion was retained for those objectives which require interaction/discussion between instructors and students, and among students.

INSTRUCTIONAL STRATEGY

Strategies within instructional blocks

in which cognitive learning takes place were presented in the previous section (i.e., student-paced instruction, individualized presentation, and testing with immediate knowledge of results). Within practice and sortie/scenario blocks the primary strategy was hands-on learning with immediate knowledge of results available either through instructor feedback or the automated performance measuring capability of the OFT. Pacing in practice and sortie/scenario lessons was based on instructor evaluation of trainee performance.

Guidelines used in the sequencing of instructional blocks were derived from the principles of learning. These guidelines pertain across the spectrum of training objectives, and when implemented, provide for the logical ordering of instructional blocks to produce an efficient and cost-effective learning sequence. One of these guidelines, which was discussed above, is early hands-on learning. This philosophy of active participation results in superior training effectiveness through increased attention and motivation and by giving the trainee the opportunity to integrate cognitive training with hardware experience.

The principle of presenting new information that is associated with previously learned concepts is well-documented in the literature. The general result of adhering to this principle is that a context is provided within which the new information becomes more meaningful. A term used within the SAT methodology is the "enabling objectives hierarchy." Prerequisite (enabling) skills and knowledges are usually acquired in simple devices (e.g., a carrel) and are later integrated into a more complex skill in a more complex device (e.g., the Tactics Trainer).

By interspersing hands-on lessons among cognitive lessons, retention of both the knowledge and the skills exercised in implementing the knowledge is enhanced (i.e., one learns by doing). Practice lessons are spaced within the course sequence so that, whenever possible, the knowledge learned in the immediately preceding cognitive lesson(s) is implemented. Sortie/scenario lessons generally build on the preceding practice lessons and provide the trainee with the opportunity to integrate the knowledge and skills acquired in the cognitive and practice lessons.

There is an apparent conflict between the sequencing philosophy in which device utilization is integrated throughout the course sequence and the sequencing philosophy in which the complexity of devices used increases as an ordered training sequence proceeds from cognitive, to practice, to sortie/scenario. This is particularly true with respect to aircraft utilization during pilot training. If the building philosophy were strictly followed, aircraft sorties could not begin until all cognitive training and early hands-on training in ground-based devices are completed. Such a sequencing strategy would be based on the argument that efficient aircraft utilization is a function of the completeness of prior cognitive learning and practice. The benefits to be derived from integrating aircraft sorties into the total training sequence is superior to the sequential ground-then-flight phase approach which is currently being used in the E-2C training program. The rationale for integration of aircraft sorties into the total instructional sequence is based upon three learning guidelines. One such guideline is that training requiring the most practice should start early in the training sequence. Certainly learning to control the aircraft in a wide variety of situations is the most difficult aspect of any pilot training program; and, therefore, experience "at the wheel" should begin early in the training sequence.

A second guideline relates to the fact that learning and retention generally increase as the fidelity of the framework in which the learning is used increases. That is, as knowledge and practice in the ground-based portions of the training sequence are accumulated, they can be utilized in the "real-world" environment, thus facilitating the acquisition of new skills and knowledge and enhancing the retention of previously-learned skills and knowledges.

A third guideline involves the effect of motivation on trainee performance. For a pilot trainee there is no motivational substitute for allowing him to do what he came into the program to do, fly the airplane. By scheduling sorties throughout the training sequence, trainee motivation will be enhanced during all portions of the training program. Motivational considerations also apply to the integration of "real-world" experience into the NFO training sequence; however, the desirability of a totally integrated sequence, in which the E-2C is extensively used, is reduced due to the high degree of fidelity attainable in the Tactics Trainer.

Fidelity refers to the "realism" of the simulation. Even though the specifications for the OFT call for a high degree of realism in all aspects of the simulation, integration of sorties into the training sequence is necessary to ensure transfer of training to the aircraft, and for instruction in phases of flight that cannot be adequately handled in the OFT. The high fidelity of simulation in the Tactics Trainer results in the capabilities for the simulation of tactical situations

superior to that in the aircraft. For this reason, Tactics Trainer practices and scenarios are integrated into the instructional sequence with aircraft missions being incorporated toward the end of the NFO/FT training course. These aircraft missions will acquaint the trainees with the intricacies of airborne tactical data (ATDS) operation in the "real-world" environment (e.g., radar presentations).

Another guideline that results in increases in trainee motivation and facilitates learning is spaced practice (as opposed to massed practice). This guideline pertains to both material and devices. That is, trainee boredom, accompanied by a resultant decrease in performance, can result from a long exposure to the same material or a long period of time in the same device. Hence, every opportunity was taken to ensure that the student is exposed to a varied media mix.

The guidelines discussed above apply as general sequencing rules across the entire instructional program and, on a smaller scale, to sequencing within modules. (A module is a series of lessons grouped by subject content area.) The sequencing among modules is based upon the factors of difficulty, criticality, and frequency of occurrence. Essentially, difficulty of the learning involved, criticality of the learning to mission success, and the probability of occurrence of an event impact upon the placement of different modules within the overall course sequence. For example, instruction on engine operations should occur early in the training sequence because (1) understanding engine operation and learning the normal and emergency engine procedures is a difficult topic area, (2) proper engine operation and responses to abnormalities are critical to the mission, and (3) the knowledge of engine operation is frequently used in both normal and emergency situations. On the other hand, instruction on the automatic flight control system (AFCS) may come later in the sequence because (1) operation of the AFCS is relatively simple (2) the AFCS is not critical to mission performance, and (3) the training orientation is not to use the AFCS during most of the sorties.

The resultant basic structure of the pilot and NFO training sequences is one of "systems within mission context." That is, systems knowledge is integrated into the sequence as the trainee is learning and performing the E-2C mission. As discussed earlier, this approach involves early hands-on learning in which the trainee first learns operating procedures, then practices the procedures, and finally performs the procedures in more complex situations in which decisions and integration with other systems procedures are required.

DISCUSSION

The individualized instructional system which Calspan has specified for the E-2C aircrew was designed to: (1) promote learning efficiencies through self-pacing, immediate feedback, early hands-on training, and criterion referencing; (2) increase instructor effectiveness through direct student contact (one-to-one) as needed; and (3) enhance training system operations through flexible scheduling. To accomplish these goals, tape/slide presentations have been selected for the primary instructional media, with self-scoring answer sheets serving the testing function. The tape/slide presentations allow for standardization of the curriculum, multiple sensory stimulation, and relative ease of incorporating changes. The self-scoring answer sheets provide immediate feedback, while maintaining a record of student performance for instructor evaluation. This approach was followed in the development of a computer managed instructional system for Navy technical training. While the small student flow rate of the present and projected E-2C program does not warrant computer support at this time, the system is amenable to that additional support, should it become appropriate in the future. A low cost computer managed instruction (CMI) terminal for support of a small learning center is already on the market, and improvements are developing rapidly. While impressive advances have also been made in other technologies, such as computer aided instruction (CAI), the clear advantage of CMI is its cost-effectiveness (Hansen and Fishburne, 1975). Moreover, the lack of definite empirical data demonstrating enhanced learning through direct interaction with the computer (CAI), point toward a greater justification for the recommended approach for handling an increase in trainee flow rate.

In developing the lesson specifications to support an individualized instructional system for the E-2C, the traditional steps of the ISD process were followed, but with a greater emphasis on a "system" orientation and an appreciation for the interactive nature of the developmental steps. Operational policy and economic data have contributed to the selection of training devices and their scheduling, as well as to training priorities. These factors have been carefully weighed against the data from the training analysis, especially the task analysis.

The task analysis employed in the E-2C SAT was heavily oriented toward operational documentation and was followed to the level of discrete perceptual-motor actions. This

approach was adopted for two basic reasons. First, it resulted in a mission-related basis for the analysis, while ensuring that the necessary "conceptual" systems information was documented in the data base. Consequently, it was able to encompass many important operations which would otherwise have been overlooked. Secondly, it served to educate the instructional psychologists in the E-2C subject matter domain. The Calspan team was then able to expand and verify this initial data base through interactions with E-2C training personnel.

The behavioral objectives were developed from the task analysis in a format that greatly expanded upon the traditional statement of behavior, condition, and standard. The additional effort required, however, greatly contributed to the system orientation and was directly applicable to the evaluation conditions and criteria. The mission/system orientation of the task analysis was maintained in the behavioral objectives as a precaution against the inclusion of unnecessary training objectives.

Finally, the lesson specifications were developed in a manner directly traceable to the task analysis and behavioral objectives. Traditionally, it has been at this point that other ISD efforts depart from their origin. In the present procedure, however, an effort was made to ensure continuity. Using a continuum from cognitive, to practice and sortie/scenario lessons, a performance orientation of training objectives and subsequently, lesson segments was assured. All of this has been presented in a format consistent with forthcoming instructional material.

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ACTION SPEED TACTICAL TRAINERS

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INTRODUCTION

This paper demonstrates the requirement for a shore-based Naval tactical trainer; outlines the types of training that can be conducted and the disciplines in which training can be given; explains how the trainer can be used for tactical investigations; lists the principal features of a low cost ASTT; and concludes with a short example of a tactical game.

Requirements for Shore-based Naval Tactical Trainers

Navies need a shore-based Naval tactical training facility or an Action Speed Tactical Trainer (ASTT) because of:

a. Restrictions imposed on fleet movements with the high cost of fuel oil.

b. The tremendous flexibility of the shore-based trainer and the facility with which the instructors can control the training environment.

In a single forenoon in the ASTT, students can be given experience in facing a wide variety of differing tactical problems such as they might not meet in a whole week of sea exercises. Furthermore, this experience can be extended to include situations which cannot normally be reproduced at sea; for instance, a wave attack by air and submarine-launched missiles.

Captain Stephen Roskill, in his book "The Strategy of Sea Power," draws frequent attention to the failure of Navies to study and practise tactics during the intervals of peace. To quote just one example: in a reference to the situation in the Royal Navy between the two world wars, he writes:

> "Trade protection was still regarded as being chiefly a matter of locating enemy surface raiders and bring them to book. Nor were any exercises carried out to investigate the problems of using aircraft as well as flotilla vessels to defend mercantile convoys against submarine attacks. Co-operation with the shore-based aircraft of the Royal Air Force was based on the priorities established for ship-borne aircraft, and none of the former received any training in antisubmarine tactics, in the defence of convoys, or in attacks on enemy merchant shipping."

Of course, there can be no substitute for sea training; but I believe there is a very real need for it to be complemented by shore-based tactical training. And this shore-based training needs to be introduced at regular intervals throughout the career of all line officers.

Let's look a little more closely at the type of training I have in mind. Broadly speaking, operational training can be divided into three categories:

First, Operator training, when we train the individual operator in his basic skills as, for instance, a radarman. I am not talking about that.

Second, procedural training, when we train, for instance, a CIC crew in their collective responsibilities for running a complex CIC. I am not talking about that.

The third and highest category is the training of individuals and command teams in the tactical control of the maritime forces under their command: the selection of Task Group formations and screens; redeployment in the face of differing threats; the dispatch of Surface Attack Units - when, where, whom?; radio and radar silence policies; the tactical deployment of weapons and the use of sensors. This is the style of training for which an ASTT is designed.

In the Royal Navy, the ASTT is part of the Maritime Tactical School. This has the great advantage that lectures on tactical subjects can be interspersed with practical experience on the trainer. Furthermore, student syndicates can be invited to prepare their own operation orders to meet a particular situation, and later to put these orders into practice on the trainer, where the shortcomings quickly become apparent. Subsequently, they must explain their decisions during the debriefing session. This is the real way in which lessons are learnt and ideas are developed.

There are two important requirements in an ASTT. (1) It should be inexpensive, and (2) it should be versatile, so that as new ships, aircraft, weapons or sensors are designed, or as new intelligence on potential enemy equipment becomes available, these ships and aircraft may be correctly simulated in the trainer without modification of the ASTT hardware or software.

In a typical ASTT students operate in cubicles, like the one in the Royal Navy's ASTT at the Maritime Tactical School, H.M.S. Dryad. The cubicle is fitted with general-purpose displays so that it may represent any type of ship or aircraft. No attempt is made to fit the cubicle with the specific equipment which is found in a ship's Combat Information Center (CIC). The cost of doing this plus the cost of stimulating all the different displays and readouts would defeat our fundamental requirement of low cost; and, in any case, we are training at a higher level, a level which uses as a tool in decision-making the picture which has been compiled and presented in a ship's CIC.

We use these displays to show the student the tactical situation as he would see it in real life at sea, taking into account the manner in which he has decided to use his various sensing devices. If he has chosen to keep radar silence, then he will be denied target information which is derived solely from active radar. This is done automatically by the computer. And, of course, the computer does a lot more. When assessing which radar targets would be detectable by any one cubicle, it takes into account: the radar type; the vertical coverage diagram, including horizon limitations; any sector sweep which may have been ordered; and the effect of enemy jamming.

Students in one of the cubicles of the Action Speed Tactical Trainer at HMS DRYAD

Similarly, for sonar, the computer takes into account: the sonar type; the sector being scanned; the depth of the thermal layer and, because sonar detections are never as consistent as radar detections, a probability factor which is related to a number of variables, including own ship's speed.

To enable the student to control his ship or aircraft, he is provided with a keyboard with a large number of special purpose keys which he uses to alter course, switch on or off sensors, fire weapons, release decoys, up periscope, etc. The capability of his craft is stored in the computer memory thus ensuring that he turns with the the correct tactical diameter; the targets he detects are those which are detectable by his own sensors and he cannot go on firing after he has expended his outfit of ammunition.

Also in the cubicle is a set of communications terminals. Radio nets are simulated, with computer controlled range limiting of UHF channels. Data links are simulated by allowing all ships and aircraft on the net and who are within radio range to receive the transmitted track data. Command and control orders could be added if required. Underwater telephone is also simulated. And, finally, there are internal communications in the form of intercom to the controllers in the Control Room, each of whom represents the different out-stations for one or more cubicles.

The number of cubicles fitted in an ASTT depends largely on the number of students you expect to train at any one time. The Royal Navy has twenty; some trainers have as few as six. The point here is that you don't require a cubicle for each track in the game - you could never hope to man them all. So, in a typical small ASTT, you might find eight surface ships represented by the eight cubicles. Then we use computer generated tracks, or supplementary tracks, as we call them, to represent all the enemy ships and aircraft, and all the missiles, torpedoes and other detectable weapons which may be fired during the game. These supplementary tracks are under the control of the instructional staff and can be made to manoeuvre, operate sensors and fire weapons as they would do in real life. They are a very inexpensive way of providing a full and realistic tactical environment.

Now let's look at the facilities provided for the instructional staff, or Controllers. The Royal Navy's ASTT has a control room and a separate debriefing room,

but in smaller ASTTs it is often found economical to combine these into a single room. This makes sense, because the requirements of the two rooms are in many ways similar.

Controlling a simulated exercise in the Action Speed Tactical Trainer at HMS DRYAD

Now, the principal tasks of the Controllers are to control the tempo and the running of the game and to supervise the students. Secondary tasks are to control the supplementary tracks, represent out-stations, such as the bridge, etc., and to impose casualties. So it is important that controllers are relieved of all procedural chores, such as assessing who can detect which targets, or guiding a missile along a predetermined flight path. This of course is where the computer comes in. As in any well designed system, it is made to perform all the functions which do not require human judgement, such as the movement of all tracks in accordance with their ordered courses and speeds, the detectability calculations to which I have already referred and the processing of information for showing on the displays in accordance with the operator's requirements.

Controllers must of course be provided with display consoles with keyboard and tracker ball. This was the console arrangement for the DRYAD ASTT, but subsequent developments in display technology have allowed this 26-inch tube to be used as a combined labelled plan display and tote. This is very much liked by controllers since it provides all the information they require on on a single display.

As I have said, it is important that controllers are able to supervise the actions of the students. To enable them to form sound judgements, it is important that they are able to see the tactical situation as this is known to the students in the cubicle. This they can do by switching their control display to show the picture as seen in any selected cubicle.

Whilst their display is so switched; or, indeed, if they choose to switch their display to a short range scale to examine some situation in greater detail, they will be blind to the overall game situation. So there is provided at one end of the control room a large screen display, visible to all controllers, on which is shown the complete game situation, with all tracks moving in real-time. There are many types of large screen displays on the market - one popular in U.K. at the moment is this one which uses Schmidt optics principles and which can be used for monochrome or multi-colour projection. With multi-colour, there may be a small problem of registration at the extremities of the display. Otherwise, it has tremendous attractions.

Another advantage of the large screen display is that spectators, and indeed students from cubicles which have been sunk, can watch the progress of the game without inconveniencing the controllers.

And of course the large screen display is essential for debriefing, which explains why I mentioned earlier that it is often found convenient to combine the control and debriefing rooms into a single room. In fact, the only reason for requiring two rooms is to allow debriefing of one game to run concurrently with the playing of another.

Debriefing is a very important aspect of tactical training. This is the occasion when students must stand up and account for their decisions, when discussion stimulates thought, and when lessons are learnt rather than just heard. To provide a background against which these dicussions can develop, and to provide a pictorial record of exactly what happened so that students can see where they went wrong, the large screen display is needed.

During the playing of the game, the movement of all tracks is recorded so that the game may be replayed on the large screen display for debriefing. It is normal to be able to rerun the game in real-time or at speeds up to sixteen times faster so as to pass quickly over the dull periods; and also to be able to stop at any selected time in order to discuss a situation of particular tactical interest.

The trainer can also be used for tactical evaluations. Let us suppose one wants to test the operational concept for, and indeed the value of, a small aircraft carrier carrying a mixed group of VTOL aircraft and helicopters in differing operational scenarios. The staff of the tactical school prepares the scenarios and experienced officers from Fleet or Squadron staff, or from the school, prepare their operational plans and then man the cubicles and fight it out. The same scenario can be played a number of times with different officers taking different responsibilities. From this, a clear lesson almost always emerges. Similarly, tactical procedures can be developed. For instance, a small Navy not fortunate enough to own a nuclear submarine can develop tactics for containing and attacking these difficult targets. One is not restricted to ships which already exist. The computer memory can be fed with the characteristics of a vessel not yet on the drawing board, or one from a bygone age: the allocated cubicle will have the capability exactly as defined, and the information is entered as data, not as a program, so there is no risk of consequential programming problems.

Of course, the ASTT can be used for any type of tactical training, be it Carrier Task Force, ASW, convoy work, amphibious, etc.

CONCLUSION

So often we have entered a war ignorant of or ignoring the tactical lessons learnt, often at great cost, in previous conflicts. I believe very strongly that an ASTT along the lines which I have described provides an inexpensive, versatile and very effective tool to ensure that we never again fail in this aspect of our Naval training.

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SIMULATION PROCUREMENT MANAGEMENT PROBLEMS AND PERSPECTIVES

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"Our job is to fool you." This statement by a senior executive of a simulator manufacturing firm neatly summarizes the accepted essence of training through simulation. Such a succinct statement, however, tends to mask the enormity of the task of synthesizing the training environment realistically enough to ensure a positive transfer of training, while keeping costs within reason. Industry has risen to the technological challenge by developing training media which, for the most part, faithfully perform according to our specifications. Although a portion of the quantum jump in training technology resulted from a wartime economy and the national space effort, most military applications were fostered by the energy crisis. In 1974 and 1975, there was an unprecedented infusion of funds into our simulator acquisition program. During this period, the Congress came to the realization that simulators could be used for substitution of flying hours, rather than simply supplementing them as in the past. The airlines had been doing it for years! Why was the military so far behind? All required forces were not acting simultaneously to create the utilization paradox that presently confronts simulator procurement managers.

FLIGHT HOUR SUBSTITUTION

The present generation of high-performance, super-complex, multimission aircraft demands more hands-on training than ever before, while at the same time flying hours are being reduced to conserve resources. The solution is obvious: use simulators as a replacement for flying hours. From the knowledge that simulators could be used for flight hour substitution grew the dictum that simulators would be used for flight hour substitution.

The requirement for flying hour substitution embodied the need for faithful replication of the training environment and this translated itself into higher procurement and support costs. The aircraft interior and its interactive forces had to be fully and faithfully replicated to justify substitution.

The budget analysts at the Defense and Congressional levels soon realized that the cost of flying hours saved as a result of simulator training could be used to amortize the cost of the simulators. The next step was unfortunate but inevitable: budgetary considerations began to take precedence over training considerations until now a procurement is approved or disapproved solely on the basis of its amortization period.

TRAINING EFFECTIVENESS

Training program sponsors are asked by the user, and directed by the Armed Services Committee, to acquire on the basis of training effectiveness. Their primary concern is the maintenance of fleet readiness. Budget analysts and the Appropriations Committees, on the other hand, approve programs primarily on the basis of cost effectiveness. Figure 1 depicts the problem:

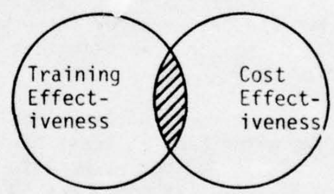

Figure 1.

The greater the number of flying hours substituted by a trainer, the greater its likelihood of survival at the budget table. There are cost-effective devices and there are training-effective devices, and very often they have little in common. Fortunately, there are a sizable number of training devices in the field and yet to come that are solidly located in the effectiveness intersection. These are the devices that are presently capable of surviving the budget process. Further, unless opinions change dramatically, only those devices which are in the intersection will be worth the effort required to sponsor them in the budget arena. Clearly, the objective of the training sponsor must be to increase the size of the overlap; increase training effectiveness and reduce costs to the point where a device will be in the intersection and, thus, fully effective.

The odd relationship of simulator training to the rest of the defense program is shown in figure 2.

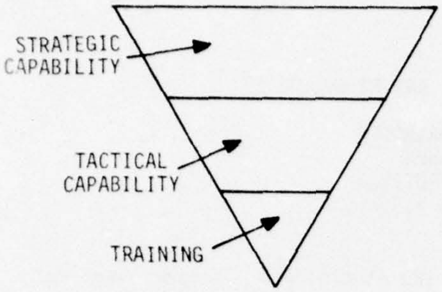

Figure 2.

Strategic capability rests on a foundation of tactical capability, and both grow from training. Aside from confrontation, the military is constantly training to be fully prepared to win those confrontations. Although training is only a rather small element of defense budget, it is the only element expected to pay for itself! Trainers which were previously considered essential to fleet training in the safe and effective operation of combat aircraft have been disapproved by reviewing authorities because they do not amortize well! B-52, C-5A, F-14, and S-3 aircraft are not expected to amortize, but the trainers for these weapons systems must do so, or risk being cut at the budget table.

These are the facts of life, and we must learn to live with them, at least for the time being. It is not our purpose to bemoan the passing of the loose money era, but to propose methods by which cost effectiveness may be increased while simultaneously improving or, at the very least, not decrementing training effectiveness.

INSTRUCTIONAL SYSTEMS DEVELOPMENT (ISD)

A step in the right direction is the concept of Instructional Systems Development (ISD). Of all the jargon and acronyms in our inventory, certainly ISD is the current leader in misuse. ISD is not a product; it is a process. One does not deliver an ISD; one delivers an instructional system as a product of the ISD process. Above all, one does not develop an ISD. Theoretically, the ISD process is one by which we may identify training objectives and deliver, or at least recommend, a homogenous training package that will enable us to meet those objectives.

In practice, however, we have paid our money and taken our chances. To date, the ISD process has produced everything from "literature searches," which have been little more than cut-and-paste exercises using the GSA catalogs, to scholarly, innovative studies, proposing a skein of media that would cost several fortunes to acquire. We are learning though, and we are narrowing the gap between what is desired and what is delivered.

Among the things that ISD is trying to tell us are some obvious ones, such as it is more cost effective to train several students or crews in part-task trainers than to train a single student or crew in a full-blown Weapons Systems Trainer (WST) on a task that only uses a small percentage of its capabilities. ISD may reinforce the need to have a WST for total mission training, but almost certainly it will also tell us that it is neither cost nor training effective to meet only limited training objectives using a fully capable WST. In reflection, ISD may actually be nothing more than the application of training common sense. ISD, in any event, is the process by which we may well demonstrate training effectiveness as well as cost effectiveness.

COST EFFECTIVENESS

There is no reason to assume that fuel costs, or any other expenses for that matter, will decrease, so the cost per hour of aircraft operation will undoubtedly continue to increase. While this increase makes more attractive the lower operating costs of simulators, it may not be enough to support acceptable amortization. Even with increased aircraft operating costs, the only thing that will guarantee a trainer's cost effectiveness is a dramatic reduction in present day procurement and support bills. We can hear you now, "You can't get there from here!" True enough! True, at least without a radical departure from "business as usual." That departure is precisely what this paper proposes.

It will be no revelation to most to state that much of the high cost of acquisition and support can be laid at the doorstep of the Government. Over the years we have developed a network of Military Standards that have, in many cases, little or no effect on hardware capability. But they have a marked effect on soaring acquisition and support costs. As Senator Lawton Chiles has pointed out, you can build a better mousetrap, but you won't be able to sell it to the Government for less than twenty dollars! And in the halcyon days of unlimited spending, we probably would have bought it for twenty dollars!

MILSPECS

Let there be no mistake about what we are saying: Military Standards have been developed in a systematic way to help guarantee the best, safest, and most reliable piece of equipment possible. The successful prosecution of modern warfare demands reliability, and Military Stan-

dards provide the means to ensure that end. Our point is this: except where safety is a factor, Military Standards have only limited application to trainers that will never be exposed to the rigors of warfare. Insofar as reliability and maintainability are concerned, no commercial firm worth its fiscal salt would buy a flight simulator that operated "in the red." Our counterparts in the airlines have been using simulators for years, cost effectively and training effectively, but without Military Standards. Now that's hard for a good military man to believe!

BUY COMMERCIAL

The idea of buying commercial is not new, but it has made little headway against the inertia (dare we say the simplicity or even lethargy?) of specifying to Military Standards. As early as 1972, Senator Chiles' Commission on Government Procurement promised strong, continued Congressional support for revised procurement policies. To put teeth in that promise, the Commission also proposed the establishment of the Office of Federal Procurement Policy (OFPP) within the Executive Branch. The OFPP has recently bared those teeth in memoranda to the Secretary of Defense, and other agencies, recommending (the Government's euphemism for "do it") that, where and when possible, the Agencies buy commercially available, off-the-shelf products and, further, that commercial distribution channels be used to supply these products to their users.

More to the present point, however, is the OFPP guidance for developing new specification standards and practices. The guidance is an amplification of recommendation made by the Commission on Government Procurement that the Government specify performance rather than design.

The unfortunate habit of writing "tight" (read design) specifications heavily laced with Military Standards has kept many qualified bidders out of the marketplace, and has often placed the Government in the position of having to buy sole source, a position frowned upon by the GAO and the Armed Services Procurement Regulations (ASPR). In point of fact, both ASPR and logic state that competition is the name of the game, and it seems clear that if we were to write performance specifications allowing industry the latitude of innovation, we would see considerably greater response to our requests for training effective proposals.

DESIGN TO COST

Now for another not-so-new idea: designing to cost. It would be naive not to admit that for years industry has been building to cost. However, neither side has been willing to admit that both were equally aware of budgeted and target dollars. It is reasonable to presume that the candor of requests for design-to-cost proposals tied to performance specifications would generate a more competitive market and, as a result, a better product for the money. In addition to the obvious benefits, design-to-cost packages will enable the contracting officer to award on the basis of quality rather than low bid.

Admittedly, the new look in trainer acquisition will require changes in legislation, policy, and administration, but we already enjoy the full support of the Legislative and Executive branches of Government, and the need for quality training has never been greater.

TOTAL EFFECTIVENESS

Our job is to provide the most effective device at the lowest cost. Heretofore we have been, for the reasons stated, myopically preoccupied with cost effectiveness. Myopic to the extent we have evaluated the cost tradeoffs we can effect through simulation to the nearly complete exclusion of attempting to optimize the true cost of a given device. We have become enamored with the flight hour subsitution that we can effect to the exclusion of all else.

We have nearly forgotten our primary need for effective training. *After all, a training device is nothing if it doesn't train.*

TRAINING EFFECTIVENESS

Cost effectiveness discussions please us; we are comfortable in them. One reason is that we have an accepted unit of cost effectiveness measurement - the dollar. But what is the unit of measurement for training effectiveness? Learning objective? The marginal propensity for knowledge? Training transfer - that's it! But how do you measure training effectiveness? The unit of measurement doesn't yet exist. The Educational Specialists are frantically in search of such a unit.

CREATE AN ENVIRONMENT

But we in the training business do have a ready made unit we can intuitively relate to until the Educational Specialists fill the analytical gap. The unit to which we refer is user acceptance. Where it is high, utilization of installed devices is high. Where it is low, the inverse is true. Where devices have been acquired to create a badly needed tactical environment, utilization has soared. Where devices have been provided solely for reduction of flight hours, unprodded utilization has been nearly zero.

One of the most illogical premises with which we deal today is that which states "an increase in fidelity, complexity, or duplication perfection is axiomatically an increase in training effectiveness." The inverse is undoubtedly true in many cases where one seriously evaluates the device's true contribution to training effectiveness.

A NEW BALL GAME

But all is not lost. We can hold on to our present advantage if we take the time to develop a plan for the future. In a sense, our situation is similar to that of a struggling football team at half time. We have weathered the first half, the period of buying for the sake of savings. Now we must revise our game plan. We need a plan that more effectively recognizes training objectives realizing that the only thing that can sustain us in the long run is a program that is built upon a continual awareness of our training needs.

The challenge is open to Government and industry alike, and the stakes are high. If we do not work together in this new direction, our failure to do so can only be measured in terms of reduced fleet readiness; an unacceptable result.

We pledge our efforts in determining and seeking procurements to fulfill only those operational requirements that are effective from a training standpoint. We enjoin you, contractor and military procurement personnel alike, to pledge your efforts, expend your energy, and use your imagination in affecting quantum improvements in cost effectiveness.

The problem is summarized in the retiring remark of an old but very wise procurement officer who said: "a trainer isn't a trainer if it can't train -- but a trainer isn't if I can't buy it.!"

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USING CAI TO MEASURE TEAM READINESS

NORMAN COPPERMAN
Honeywell
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PAUL ASA DORIAN
FLEASWTRACENPAC

COMNAVSURFPACINST C3590.1 requires for all ASW platforms a four-phase ASW training and readiness improvement program, with the first three phases conducted at FLEASWTRACENPAC and the fourth phase conducted at sea. This instruction requires that "All training conducted . . . be evaluated and assigned a numerical grade. In addition, the ship will be provided copies of detailed grading sheets on each team member."

Phase I, Basic Attack Team Training, consists of two days for ships equipped with AN/SQS-23 and three days for ships equipped with AN/SQS-26. It involves classroom instruction in terminology, plotting, tracking, classification, search, localization, and single ship attack procedure. It also includes trainer problems that begin with single ship/single target and progress to dual ship/aircraft coordinated operations (including CZ and LAMPS), culminating with graded attack exercises. The 14A2 ASW team trainer is the backbone of the training program.

Surface Ship ASW Attack Trainers of the 14A2 Series are essentially shorebased ASW tactics training systems that provide full simulation of the sensors, tracking, fire control and weapon deployment systems normally provided on ASW ships of the fleet. Device 14A2 simulates the entire ASW tactical situation, from submarine target acquisition, through tracking, fire control solution, and weapon firing. It simulates own ships, targets, and weapon ballistics, using a general-purpose digital computer to generate and control problems.

The present method for measuring performance is broken down with the following weighting factors:

ASW ESCORT QUALIFICATION PROGRAM
K-000-1070 (PHASE I)

Performance Measuring and Reporting Guide

Position	Points
Command/Evaluator	28
Bridge	4
Sonar	8
Underwater Battery Plot	12
CIC (General/Plotting)	12
Air Control	16
Weapons	20

Penalty Factors to be Applied to All Final Evaluations

-5 Simulated weapons launch such that friendly unit(s) are endangered.

-5 Failure to attack submarine prior to submarine attack on friendly unit.

-3 Improper sound-powered phone procedures and failure of controlling station in maintaining proper discipline.

Overall Grade______

This program is designed to maintain and, if possible, improve fleet readiness. But does it? The answer is a disquieting, "We don't

know." The reason for the difficulty in determining the degree of fleet readiness in ASW operations is that the validity of the scoring system used for measuring team performance is questionable.

At first glance, the indisputable scoring tends to obscure the fact that some aspects of performance are so loosely defined that they are subject to varying levels of interpretation by different instructors at different 14A2 sites. Currently in the 14A2 trainers, adequacy of performance is determined by the instructor, based on his individual judgment, because objective measurements, methods, or criteria for the ASW team are nonexistent. In Figure 1, for example, it is hard to imagine that all instructors on East and West coasts will agree on the proper forming up of the SAU and the correct spacing of units, particularly since there are no standard scenarios.

A valid scoring system requires the use of objective methods to evaluate training. However, the problem of developing objective performance criteria for evaluating surface ASW team training is an elusive one. The problem is compounded by the lack of specific training objectives that can be readily converted into measurable criteria. The remainder of this paper addresses certain techniques explored for establishing an objective basis for ASW team evaluation.

PROBLEM

The development of a system based on objective criteria for training and evaluating ASW team performance represents a sizable undertaking. The first step has been one of data collection and analysis. The goal for this phase was to determine what computer aids could be developed to help make more objective the evaluation of team performance. A ground rule during this phase was that training practices were not to be considered as variables but were to be defined as presently employed.

APPROACH

Computer representations of several training sessions were "captured," and various computer techniques for evaluating team performance were explored. The 14A2 computer program was modified to dump to magnetic tape, on a second-by-second basis, the computer system parameter tables. With this modified program, tapes containing all relevant variables that would be available at the time of training were generated at FLEASWTRACENPAC from normal training sessions. In addition, a system of programs was developed for scanning the tapes for particular performance variables and for providing output in suitable formats.

This approach permitted an empirical determination of an analysis technique tailored to the special requirements of ASW team training.

Computer assessment of performance must rely on performance criteria that are specified in terms of computer representations. If the assessment is to be meaningful, these criteria should be valid over a reasonable range of possible training problem scenarios. Under prevailing training practices, it would appear virtually impossible to derive a set of such criteria.

As Device 14A2 is currently used, problems are specified in terms of the vehicles involved and their starting configurations. As a training mission progresses, problem variables change in a freely developing manner. Performance criteria derived on the basis of such a problem specification and valid over the entire range of possible outcomes would be very difficult to imagine. Even if problems were completely "canned" except for own ship parameters, the derivation of criteria would remain indeterminable. For every such canned problem, there are a number of possible tactics, and these tactics can define contrasting sequences of tasks for team members. With any conceivable set of criteria, significant errors in evaluation could result. Any practical computerized scoring system would not be able to adjust to the tactics used.

Although computer assessment appeared infeasible, it still seemed reasonable to assume that the computer could be a valuable tool in the assessment process. Accordingly, the problem chosen for study was the development of a display of information critical to a broad range of training problem developments. The amount of information had to be limited so that the evaluator would not be overwhelmed with it, and it had to be displayed so that performance level could be assessed with a minimum of analytical effort.

Currently, team member performance evaluation in Device 14A2 occurs in the form of a subjective post-problem critique. The analysis relies on the questionable analytical ability of team members in that, as part of the analysis, they are called upon to search their memories to try to report the causes of failures. It appeared that there was much that could be done to aid this process.

The only system-generated records of team performance are in the form of slides, which are normally lost after training. Clearly, there is room for improvement in the capability of the system to generate useful records. The computer system, in addition to its current functions, could be used to collect relevant performance data in real-time and reduce it to meaningful statistics immediately following termination of a problem. The results could be in the training officer's hands in time for his critical review. This feature would enable the training officer to derive an objective analysis of failures, independent of the biased views of the participants.

COMMAND/EVALUATOR

AVAIL.	EARNED	
		COMMAND/EVALUATOR - GENERAL
10		Was SAU Commander aware of tactical employment of all units under his command?
10		Was a low noise level maintained in CIC?
10		Was classification a continuous process by SAU Commander?
20		Were four weapon attacks successful? (An urgent attack does not need to be a hit in order to be considered successful.)
		APPROACH PHASE
8		Was Datum properly disseminated to all units?
6		Was SAU properly formed up, and was spacing correct, considering predicted sonar range?
8		Was SAU search front properly reordered and was approach to Datum proper for tactical situation?
6		Were Cone of Courses, Intercept Course, and time to enter TDA compared and concurred with Assist Ship?
6		Were appropriate countermeasures executed during Approach Phase?
8		Were Plans Red and Black and Weapons Policy passed to Assist Ship?
8		Was controlling station properly kept informed?
6		Were aircraft plots evaluated to determine target course and speed?
8		Was time to enter TDA updated with latest contact information and new Intercept Course executed accordingly?
5		SWAP SITREP requested and obtained prior to execution of SWAP.
5		SWAP SITREP disseminated to command, with State, Weapons, Contact status, and Datum information included.
7		SWAP executed in a timely manner.
5		SAU advised when SAC is assumed.
8		Zig-Zag Plan executed prior to entering TDA.
6		Appropriate Material Countermeasures prepped or executed.

Figure 1. ASW Escort Qualification Program Evaluation Form

PROGRESS

Two types of materials have been developed: a graphical representation of training problem events, and a listing of numerical information associated with critical occurrences. From a plot, the tactical situation and the performance of all subteams except for CIC can readily be determined. This graph is similar to the plot currently produced in slide form by Device 14A2, but it contains considerably more information, and it is presented in hard-copy form.

Figure 2 shows a plot of a simple exercise: single ship (own ship) with one submarine. This plot was produced from a sample of the collected computer data. The black and red trackings are the tracks of own ship and enemy submarine, respectively. Unlike the Device 14A2 slides, here time indices appear on the tracks for use in determining the relative position of ships in any problem and at any time. With very little practice, progression of the tactical situation can also be determined. On each track, positional time is indicated in minutes; the time between each subunit tick is 10 seconds. The symbol X on a track indicates the firing of a torpedo. A dashed line connecting the "fire" symbol to a small circular track depicts the flight path of an ASROC-launched torpedo. The circular track depicts the helical search pattern of a Mk 46 torpedo. The time-tagged torpedo tracks are over-the-side shots by own ship and enemy submarine.

The green track is the tracing of the sonar operator's cursor. This track represents, when systematically in the vicinity of the submarine, where in the ocean the sonar operator was specifying the submarine to be. As can be seen in Figure 2, there appears to be a constant range error in sonar target tracking, which could reflect a deficiency in the sonar operator's performance or perhaps result from uncalibrated equipment. The tracing of sonar tracking is not currently available on Device 14A2.

The blue, sawtooth-like markings that run along-side the red submarine tracing indicate computed course and speed. They are shown at all problem times, even though at various times they may be meaningless, such as computed values before initial contact has been made. At each intersection of a red time tick and the red track (at the submarine's position every 10 seconds), a blue vector is drawn, showing a predicted position of the submarine at an elapsed time of 10 seconds, based on the actual position of the submarine and its computed course and speed. Vector direction indicates computed course, and vector length indicates computed speed. At the end of the vector is a time tick. When computed course and speed are perfect, the blue and red tracks are completely superimposed. Figures 3 and 4 are further examples of training problem plots.

Figure 5 is a numerical printout designed by FLEASWTRACENPAC training personnel. The printout lists training problem information at selected times. A line of printout is generated when any of the following conditions is true:

1. (S) Sonar pulse length is changed.
2. (E) An event symbol is requested by an instructor.
3. (F) A weapon is fired by own ship.
4. (W) An ASROC-launched torpedo enters the water.

The information shown here under runs 1, 2, and 3 was derived from the data used to generate the three plots shown in Figures 2, 3, and 4, respectively.

SIGNIFICANCE OF RESULTS

With the exception of the CIC, the plots present, in comparative form, significant actions of all subteams. Shown together in a single representation, it should be possible to assess how well individual subteams performed and, more importantly, how well coordinated their actions were. With the addition of CIC plotting information, the performance of all subteams would be represented, and an evaluator could readily determine which, if any, of the subteams was responsible for failures in the team's execution of its tactic.

Immediate availability of the plots and training statics following a training session would free the instructor from many of his record-keeping tasks and allow him to evaluate team communications more thoroughly.

A plot serves as the basis of a permanent record of team performance, and a library of plots represents a fleet performance data base. Such records have potential value in several respects:

1. An incontrovertible evidence of team failures (for use when a ship challenges its performance grade).
2. A source of performance statistics, permitting an objective description of fleet readiness.
3. The means for determining the effectiveness of training methods and training devices.
4. A basis for evaluating ASW doctrine.

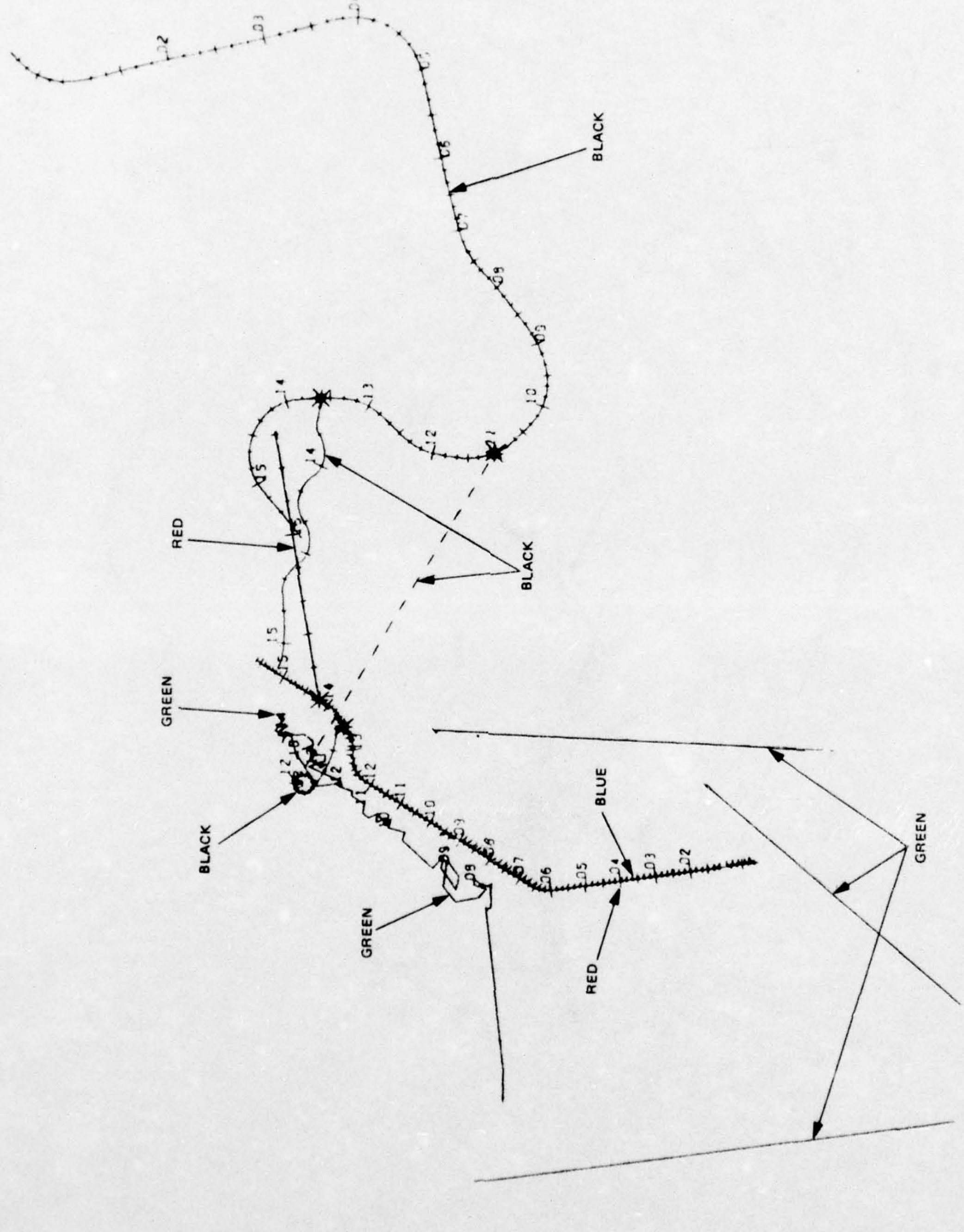

Figure 2. Training Problem Plot, Run

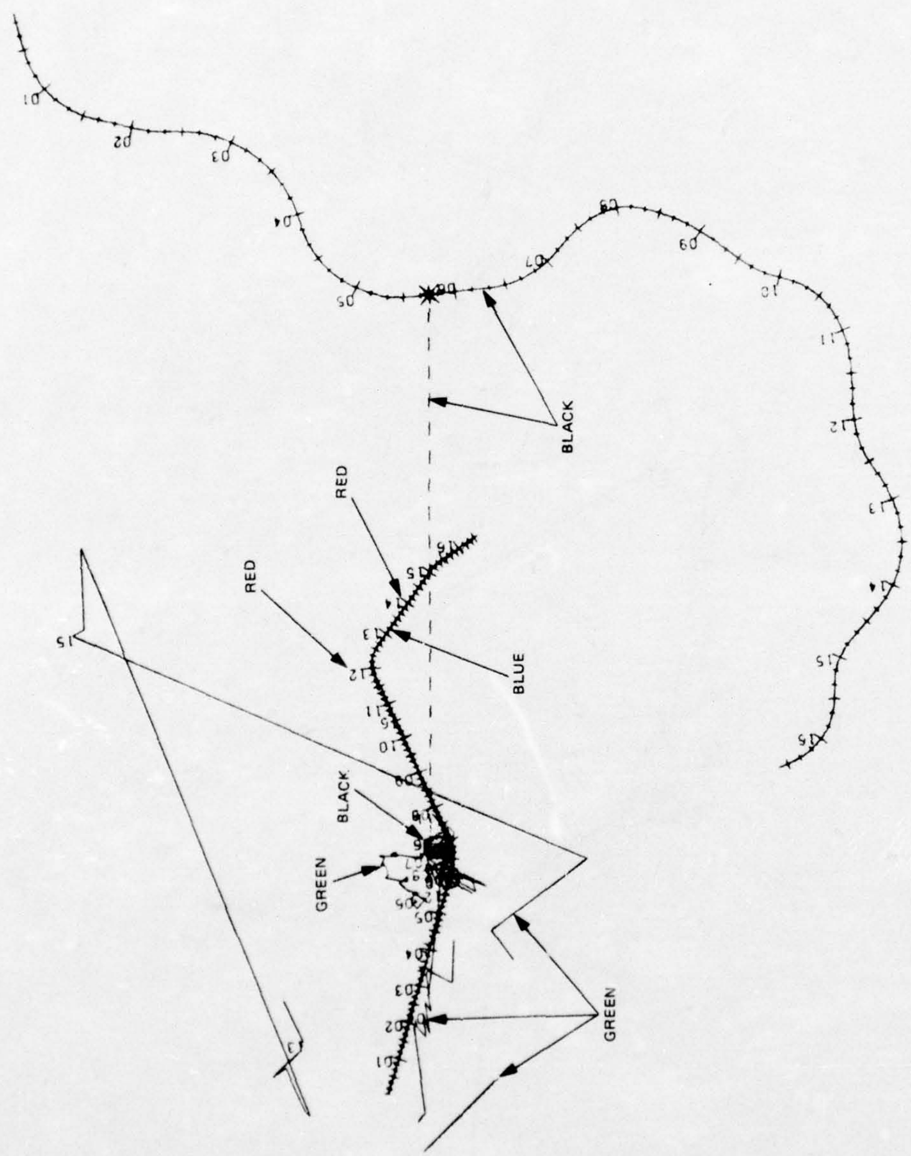

Figure 3. Training Problem Plot, Run

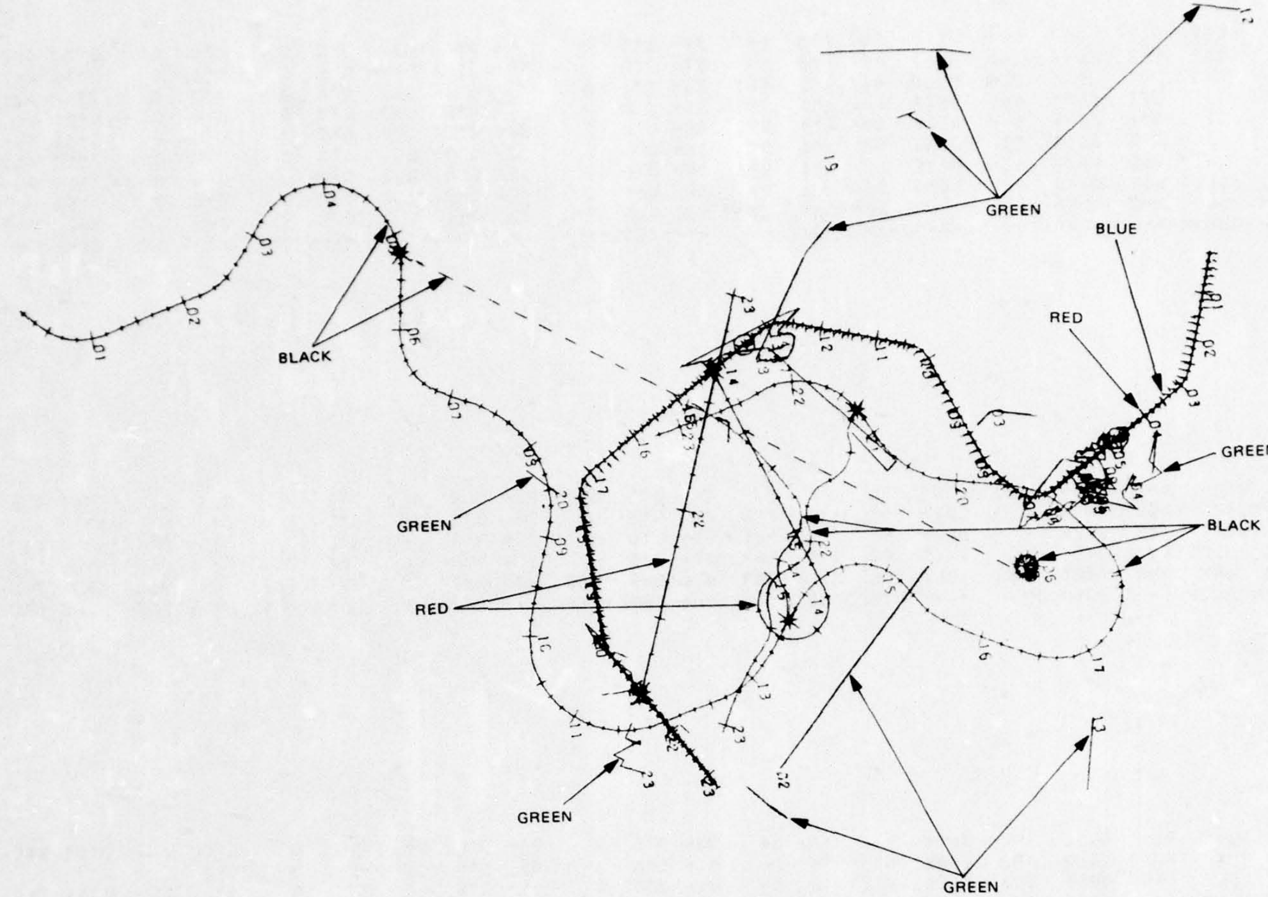

Figure 4. Training Problem Plot, Run

RUN # 1

TIME	OWN SHIP CRS	OWN SHIP SPD	SJ1 SHIP CRS	SJ1 SHIP SPD	SJ2 SHIP CRS	SJ2 SHIP SPD	----SUB1---- CRS	SPD	DEP	----SUB2---- CRS	SPD	DEP	---FIRE CONTROL--- CRS	SPD	BRN	RNG	--ACTUAL- BRN	RNG	----WEAPON--- BRN	RNG	GYR	SONAR
S 00:02	225	18.0	0	0.0	0	0.0	350	8.0	-32	0	0.0	-32	28	8.6	114	2145	225	8520	56	8465		MD
E 07:39	225	15.2	0	0.0	0	0.0	30	8.0	-16	0	0.0	-16	0	8.6	268	4975	266	4685	56	4623		MD
E 11:01	330	14.2	0	0.0	0	0.0	30	8.0	-16	0	0.0	-16	40	8.6	290	3030	283	2880	73	2843		MD
F 11:04	333	14.2	0	0.0	0	0.0	30	8.0	-16	0	0.0	-16	40	8.6	290	3005	283	2860	343	757	7P	MD
# 11:34	1	14.5	0	0.0	0	0.0	30	8.0	-16	0	0.0	-16	40	8.6	289	2840	281	2715	338	632	7P	MD
F 13:37	357	19.0	0	0.0	0	0.0	60	12.0	-16	0	0.0	-16	40	8.6	274	2690	264	2560	24	2481	7P	MD

RUN # 2

TIME	OWN SHIP CRS	OWN SHIP SPD	SJ1 SHIP CRS	SJ1 SHIP SPD	SJ2 SHIP CRS	SJ2 SHIP SPD	----SUB1---- CRS	SPD	DEP	----SUB2---- CRS	SPD	DEP	---FIRE CONTROL--- CRS	SPD	BRN	RNG	--ACTUAL- BRN	RNG	----WEAPON--- BRN	RNG	GYR	SONAR
E 03:44	334	20.8	0	0.0	0	0.0	200	8.0	-32	0	0.0	-32	133	8.6	359	6005	355	5610	165	10729	7P	MD
F 05:45	268	21.4	0	0.0	0	0.0	200	8.0	-32	0	0.0	-32	194	9.7	5	4280	3	4227	326	233	0	MD
# 06:20	267	21.4	0	0.0	0	0.0	200	8.0	-32	0	0.0	-32	162	9.7	14	4160	9	4200	151	167	0	MD
E 13:16	353	18.7	0	0.0	0	0.0	220	8.0	-32	0	0.0	-32	7	9.7	49	4680	44	4617	169	732	0	MD

RUN # 3

TIME	OWN SHIP CRS	OWN SHIP SPD	SJ1 SHIP CRS	SJ1 SHIP SPD	SJ2 SHIP CRS	SJ2 SHIP SPD	----SUB1---- CRS	SPD	DEP	----SUB2---- CRS	SPD	DEP	---FIRE CONTROL--- CRS	SPD	BRN	RNG	--ACTUAL- BRN	RNG	----WEAPON--- BRN	RNG	GYR	SONAR
S 04:21	35	19.0	0	0.0	0	0.0	150	10.0	-32	0	0.0	-32	160	9.7	30	5955	26	5880	310	13557	0	
F 05:13	90	19.2	0	0.0	0	0.0	150	10.0	-32	0	0.0	-32	166	9.7	29	5210	25	5240	344	991	0	MD
# 05:53	101	21.2	0	0.0	0	0.0	150	10.0	-32	0	0.0	-32	166	9.7	26	4885	22	4992	338	775	0	MD
E 10:42	58	19.9	0	0.0	0	0.0	200	12.0	-32	0	0.0	-32	166	9.7	348	4220	349	4492	139	1119	0	MD
S 10:45	55	19.9	0	0.0	0	0.0	200	12.0	-32	0	0.0	-32	166	9.7	348	4190	349	4492	139	1119	0	
F 13:42	309	21.2	0	0.0	0	0.0	150	12.0	-32	0	0.0	-32	166	9.7	279	2010	270	1962	90	1924	7P	MD
E 20:45	233	20.7	0	0.0	0	0.0	60	12.0	-32	0	0.0	-32	66	9.7	159	1940	149	2472	231	1973	7P	MD
F 21:17	239	20.7	0	0.0	0	0.0	60	12.0	-32	0	0.0	-32	66	9.7	145	2530	136	2567	255	2534	7P	MD

Figure 5. Training Problem Printout

PHASE II PLAN

The next phase of the program will include development of a variety of computer-based problem scenarios. These scenarios will provide a training option that should increase training problem standardization by placing target maneuvers under computer control.

At present, target maneuvers are under instructor control. Maneuvers employed in training reflect the instructors' differing concepts of submarine tactics. In addition, instructors use their individual judgment in determining how a submarine's maneuvers should be adjusted to achieve a chosen level of problem difficulty. Under these conditions, it is virtually impossible to derive performance norms to cover the range of possible tactical developments.

Standardized scenarios should permit a valid comparison of the performance of ASW teams of different ships, trained at different times, at different sites, and by different instructor staffs. The goal of this next phase will be to develop scenarios that are graded with respect to problem difficulty and that cover a representative range of tactical possibilities.

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AN APPROACH TO STIMULATION OF OCEAN MULTIPATH PHENOMENA FOR SONAR TRAINING DEVICES

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To meet the increasing threat imposed by well-equipped, modern submarines, active and passive sonar systems with highly sophisticated signal processing and display subsystems must be developed. Training of sonar operators to use these systems effectively requires simulation of actual operations whenever possible. This can be achieved by providing a training system that: (1) simulates operational equipment, or (2) stimulates the actual tactical hardware. The trainer must present the trainee with the same operating situation that he will encounter in real-world combat conditions, including the ocean acoustic model.

Training system models of the ocean acoustic environment must be adequate to represent the new sonar systems, with their increased sophistication and improved signal processing capabilities. Consequently, new and more complete acoustic environmental models, which can run in real-time, must be developed for both active and passive mode sonar systems trainers. To stay within Navy budgets, however, innovative, cost-effective concepts and designs are required for the models, as well as the stimulation hardware.

The amount of nontactical hardware required for the development of sonar training devices using stimulation techniques is roughly proportional to the number of acoustic paths that must be simulated. The sounds of all acoustic paths between a source and a receiver must be generated, frequency-shaped, attenuated, and inverse-beamformed. A reduction in the total number of acoustic paths to a subset sufficient for stimulation, while retaining the inherent attributes of the ocean multipath phenomenon and sonar capabilities, permits effective training with a minimum amount of nontactical hardware.

The objective of this paper is to discuss a concept and associated analytic processes developed for use in sonar training devices to provide high-fidelity simulation of ocean multipaths. It is shown that this technique can be used to represent the total acoustic field, using two equivalent multipath subsets.

OCEAN ACOUSTICS

Accurate representation of the acoustic field between any two points in the ocean environment requires the consideration and accurate representation of all major contributing acoustic paths between these points. As the whole is the sum of all its individual parts, the total acoustic field is the sum of the individual multipath contributions. It is well-known that, between any two spatial locations, acoustic energy can propagate along many individual paths, the nature of which is solely dependent upon the sound velocity structure of the medium itself. Typical examples of this phenomenon are illustrated in the acoustic ray diagrams and associated sound velocity profile structures shown in Figures 1 and 2. The individual ray paths joining any two points in the medium are referred to as eigenrays. It is the summation of the acoustic characteristics of each of the individual eigenray intensities that determines the field intensity at a given location in the ocean.

The summation of these eigenrays produces such well-known ocean characteristics as multipath interference regions and convergence zones. Figure 3 illustrates the acoustic field enhancement, a decrease in propagation loss, due to the convergence of the individual eigenrays.

Since it is not within the scope of this paper to delineate acoustic ray theory, a less rigorous, yet illustrative, example will be used to introduce the subject simulation problem and solution.

Consider the simplified two-boundary image model geometry shown in Figure 4. For illustrative purposes, multipaths between the source and receiver are assumed to be straight lines; six individual paths are shown. The total acoustic field (assuming unity surface reflection and constant sound speed) at any spatial coordinate is represented by the coherent sum of each individual multipath and is analytically given by,

$$\psi = \frac{e^{ik^* R_1}}{R_1} - \frac{e^{-ik^* R_2}}{R_2}\,; \quad R < 1000 \text{ yd}$$

$$\psi = \frac{V_3^* (\theta_3) e^{-ik^* R_3}}{R_3} - \frac{V_4^* (\theta_4) e^{-ik^* R_4}}{R_4} - \frac{V_5^* (\theta_5) e^{-ik^* R_5}}{R_5} + \frac{V_6^* (\theta_6) e^{-ik^* R_6}}{R_6}\,;$$

$$R > 1000 \text{ yd}$$

$$N_W = 20 \log |\psi|$$

where

k^* = propagation constant

$R_1 \ldots R_6$ = length of each path

$V_3^* \ldots V_6^*$ = bottom reflection coefficient corresponding to bottom grazing angles $\theta_3 \ldots \theta_6$

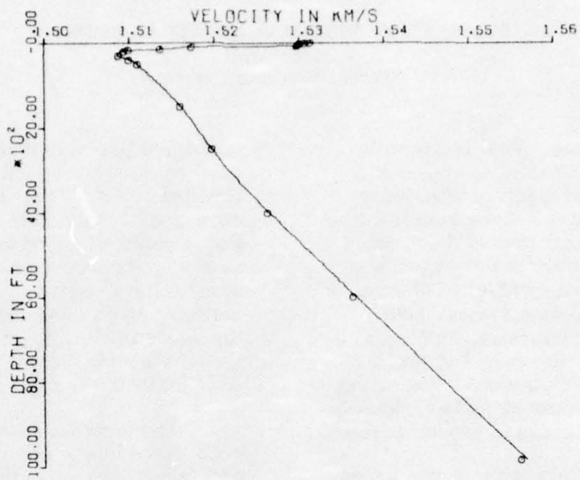

Figure 1a. Typical Sound Velocity Profile

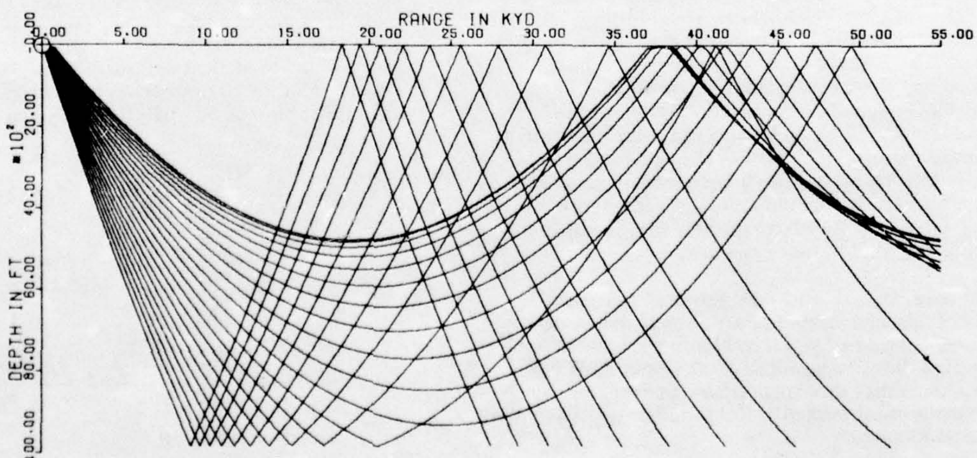

Figure 1b. Typical Acoustic Ray Plot

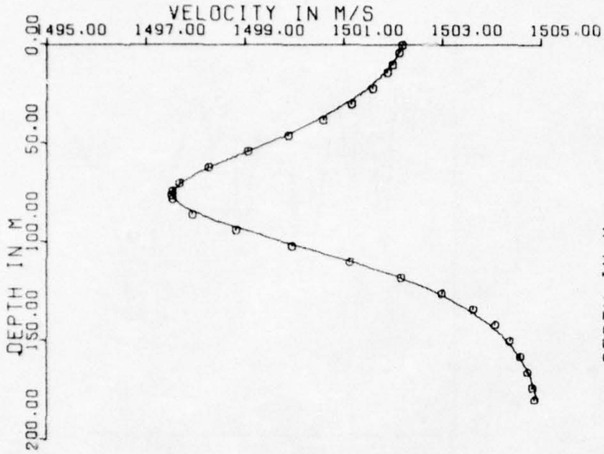

Figure 2a. Typical Sound Velocity Profile

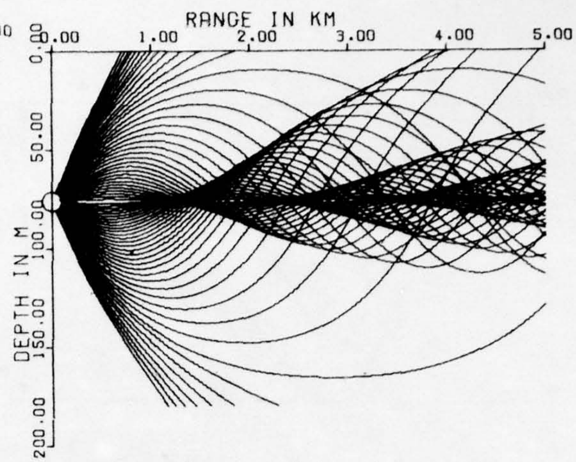

Figure 2b. Typical Acoustic Ray Plot

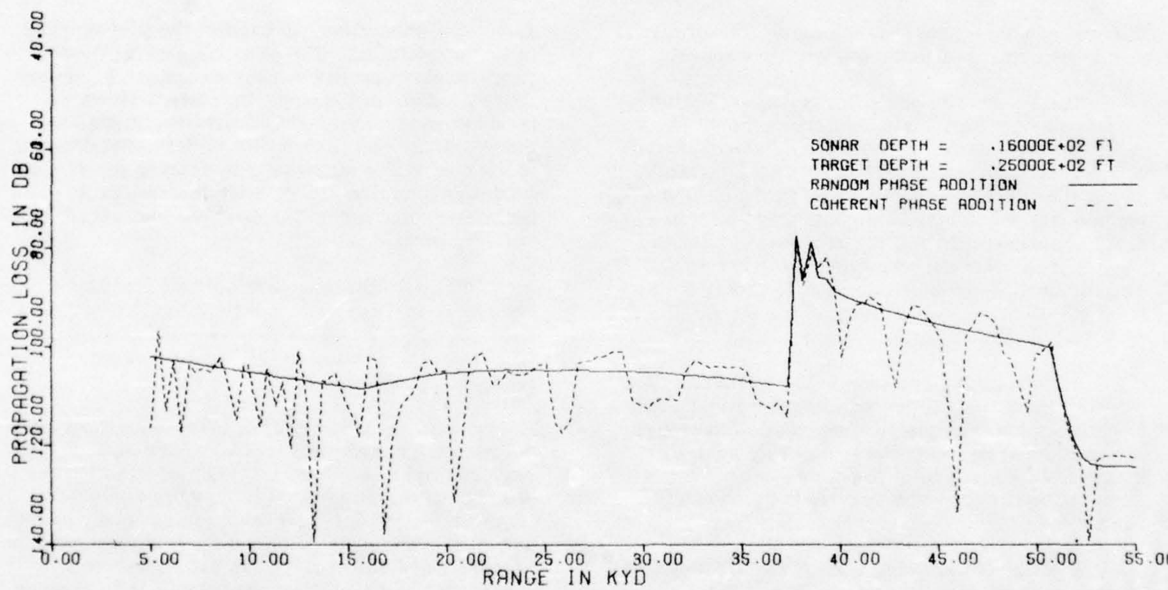

Figure 3. Typical Propagation Loss Plot Illustrating Convergence Zone

Information associated with each of these multipaths includes intensity (spreading and absorption loss, bottom and surface loss), phase, arrival angle, and travel time or differential travel time. In this example, path length and time are functionally equivalent, since a constant speed of sound is assumed. In the more rigorous sense, this is not true, since the actual acoustic energy travels along ray paths in a medium at a continuously varying sound speed.

Figure 5 illustrates a typical propagation loss output from the aforementioned image model. To provide high-fidelity simulation of ocean phenomena commensurate with the operational capabilities of the tactical hardware, the various attributes of multipath propagation, as summarized above, must be considered for effective sonar training. If the tactical hardware is sensitive to the effects of multipath phenomena, these effects must be simulated to a fidelity equivalent to the hardware capabilities.

APPLICATION

Generically speaking, sonar or nonsonar training devices can be divided into two basic categories: (1) full simulators, not employing tactical hardware; in these devices, visual and aural trainee presentations are almost completely under the control of mathematical processes; and (2) stimulators, in which synthetic signals are

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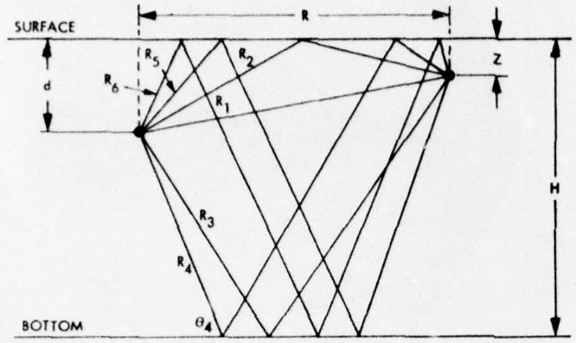

Figure 4. Two-Boundary Image Model Geometry

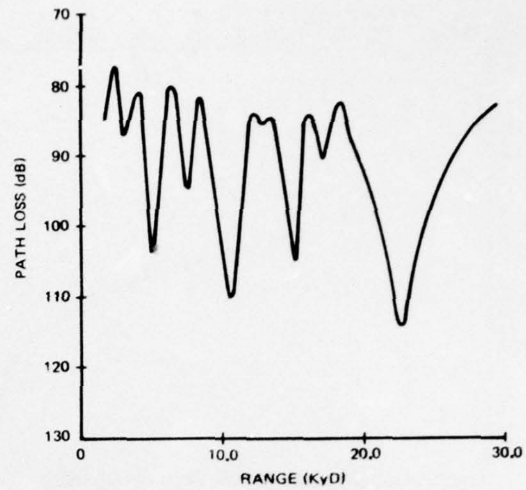

Figure 5. Typical Two-Boundary Image Model Propagation Loss Output

injected at some point into the tactical hardware under the control of mathematical processes.

The process of achieving a cost-effective trainer design often includes development of synthetic signals that do not completely map real-world phenomena but are "acceptable for training." For a sonar training system using stimulation techniques, the synthetic signals must be more nearly representative of the real-world acoustic signals if the tactical equipment is to be "fooled." The further the point of injection is moved to the front end of the system, the greater the fidelity required of these synthetic acoustic signals.

In a sonar trainer employing full simulation or stimulation with injection after the beamformer, effects of multipath phenomena can be functionally simulated and represented in a purely analytic manner, irrespective of the complexity of the mathematical processes required, as shown in Figure 6.

A sonar trainer that uses synthetic signal injection points at either the input or output of the array sensor pre-amps and depends on the sensitivity of the system to multipath signals requires the use of an inverse beamformer and associated signal generator for each target multipath combination, as illustrated in Figure 7. The inverse beamformers are required to time-orient the synthetic signals in both the vertical and azimuthal planes so that the spatial geometry of the array sensors is accounted for prior to signal injection into the tactical hardware beamformers.

ALGORITHM OVERVIEW

The primary computer program used to develop the concepts presented in this paper is the Navy Interim Surface Ship Model (NISSM) II (Ref. 1). NISSM was developed by Dr. Henry Weinberg of the Naval Underwater Systems Center at New London, Connecticut, to predict the performance of sonar systems. The program provides, as a function of ocean and system parameters, acoustic ray paths, propagation loss predictions, boundary and volume reverberation, signal-to-noise ratios, and probability of detection outputs, using continuous-gradient ray-tracing techniques. Model assumptions include horizontal ocean boundaries and a non-range-dependent sound velocity profile.

The algorithm developed for selecting "bundled" multipaths is currently automated on a CDC 6600 as part of an in-house NISSM II system. All figures presented in this paper were created from this system.

As mentioned earlier, many eigenrays exist between the source and receiver. Selection of the ray path and associated acoustic information for simulation or stimulation is, therefore, of prime importance. If selected incorrectly, many of the acoustic phenomena required for training could be inadvertently omitted. A typical selection criterior that is sometimes considered is to provide the acoustic information associated with the two strongest eigenrays. This is a good approximation if the selected eigenrays are sufficiently stronger than the remaining ones; however, it is not necessarily a typical situation. Since this type of selection process can produce significant errors in certain instances, it should not be considered the optimal approach. For example, consider the typical plot of propagation loss versus range presented in Figure 8. The solid line represents the coherent summation of path loss along all ray paths. The line broken by circles represents the coherent summation of the path loss using the two strongest rays. More significant than the errors between the two curves is the fact that they do not have the same general shape. Therefore, to provide effective training (again dependent upon the tactical hardware capabilities)

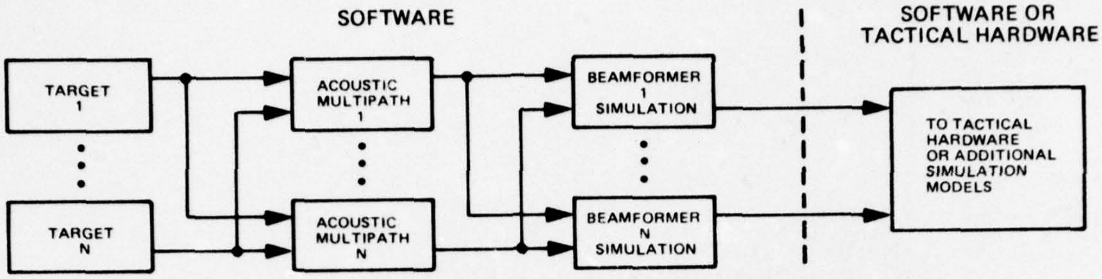

Figure 6. Target/Acoustic Path Function Block Diagram for Simulation or Post-Beamformer Stimulation Implementation

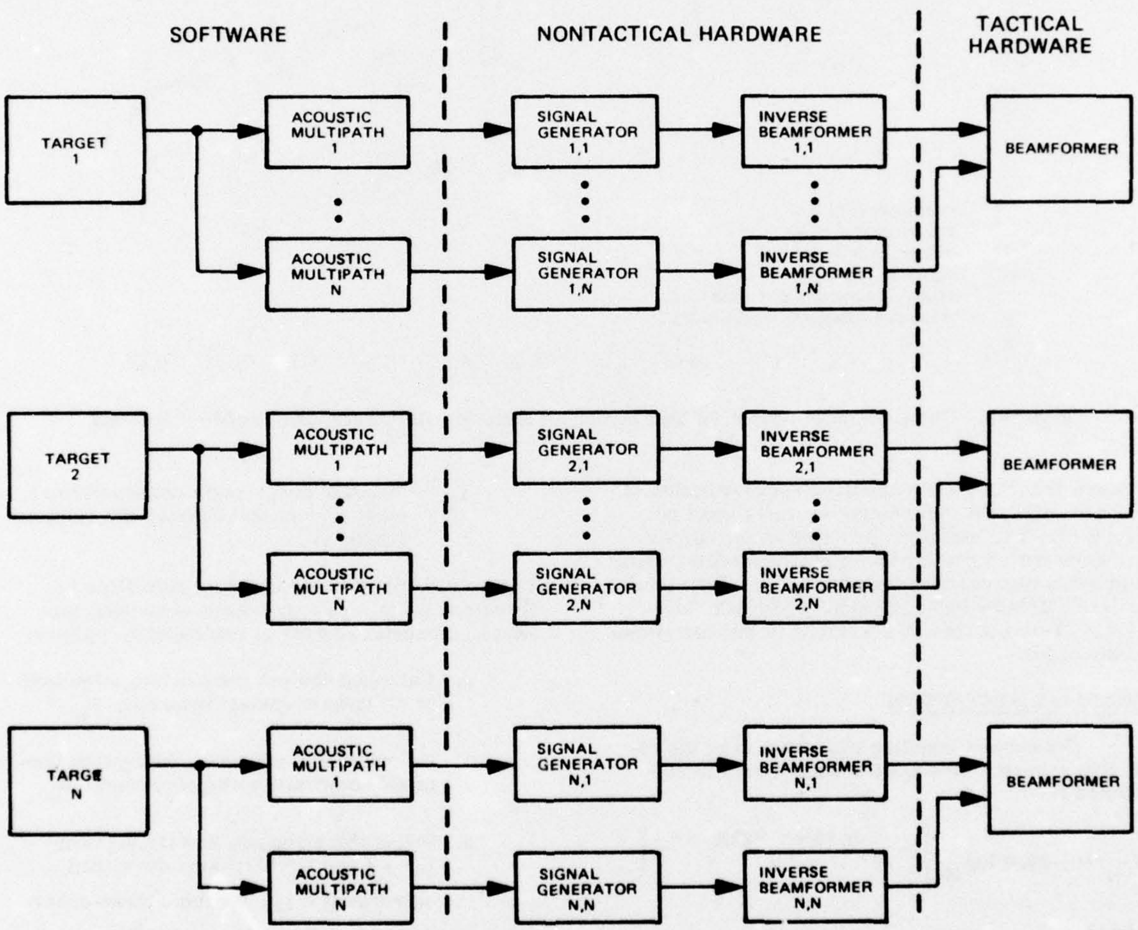

Figure 7. Target/Acoustic Path Function Block Diagram for Pre-Beamformer Stimulation Implementation

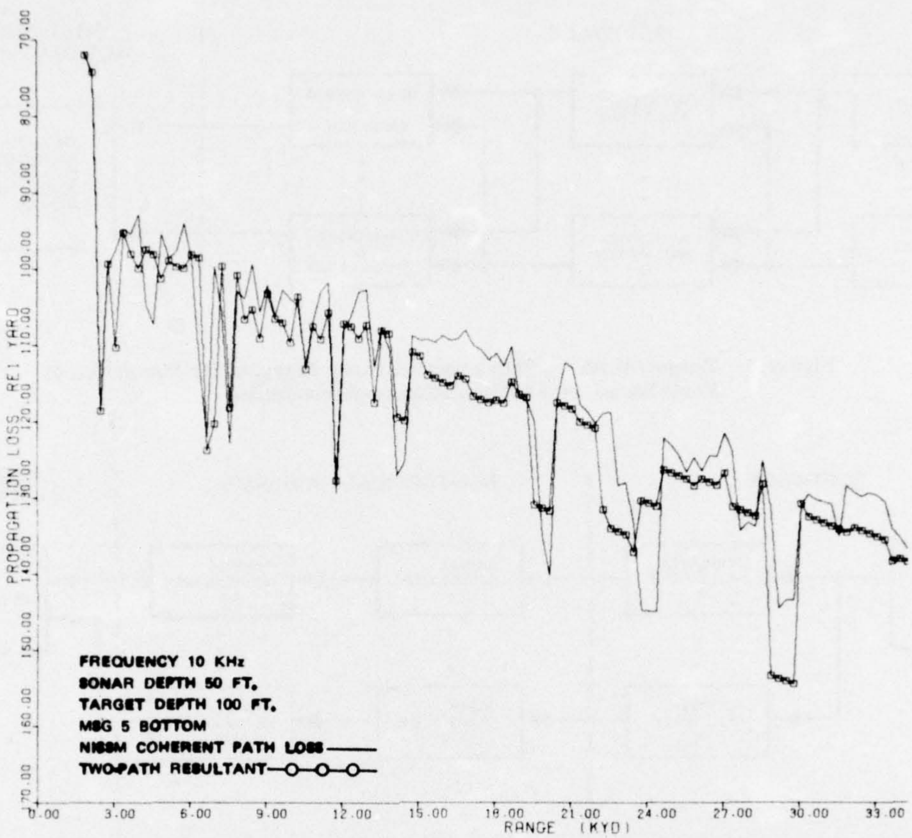

Figure 8. Comparison of NISSM vs Two Strongest Rays for Mediterranean Profile - Summer

a more accurate, cost-effective representation of the acoustic field for training systems must be provided. The technique provided in this paper provides the required cost-effective fidelity, using a process that permits representation of the total acoustic field by two equivalent multipath "bundles." This process is described in the remainder of the paper.

BUNDLING ALGORITHM

The subject bundling algorithm uses the effective coherent propagation loss, which is calculated from:

$$N_{eff} = -20.0 \log_{10} \left| \sum_j 10^{-0.05 N_j} e^{i(2\pi f t_j + \zeta_j)} \right|$$

where

N_j = propagation loss for the j^{th} eigenray (dB)

f = frequency (Hz)

t_j = travel time for the j^{th} eigenray (seconds)

ζ_j = discrete phase angle change of the j^{th} eigenray due to boundary interactions (radians).

Figure 9 illustrates the bundling algorithm in flowchart form. The algorithm to be used (except in a caustic region) is computed as follows:

a. Calculate the coherent propagation loss of all upward-going eigenrays, N_u.

b. Calculate the coherent propagation loss of all downward-going eigenrays, N_d.

c. Select the strongest upward eigenray ($j = j_u$) and the strongest downward eigenray ($j = j_d$), combine these coherently, and obtain N_1, using Equation 1.

d. Select the strongest upward eigenray ($j = \hat{j}$) such that $\zeta_{\hat{j}} \neq \zeta_{j_u}$

e. Coherently combine the $\hat{j}$ eigenray path with the j_d eigenray path, N_2, in accordance with Equation 2.

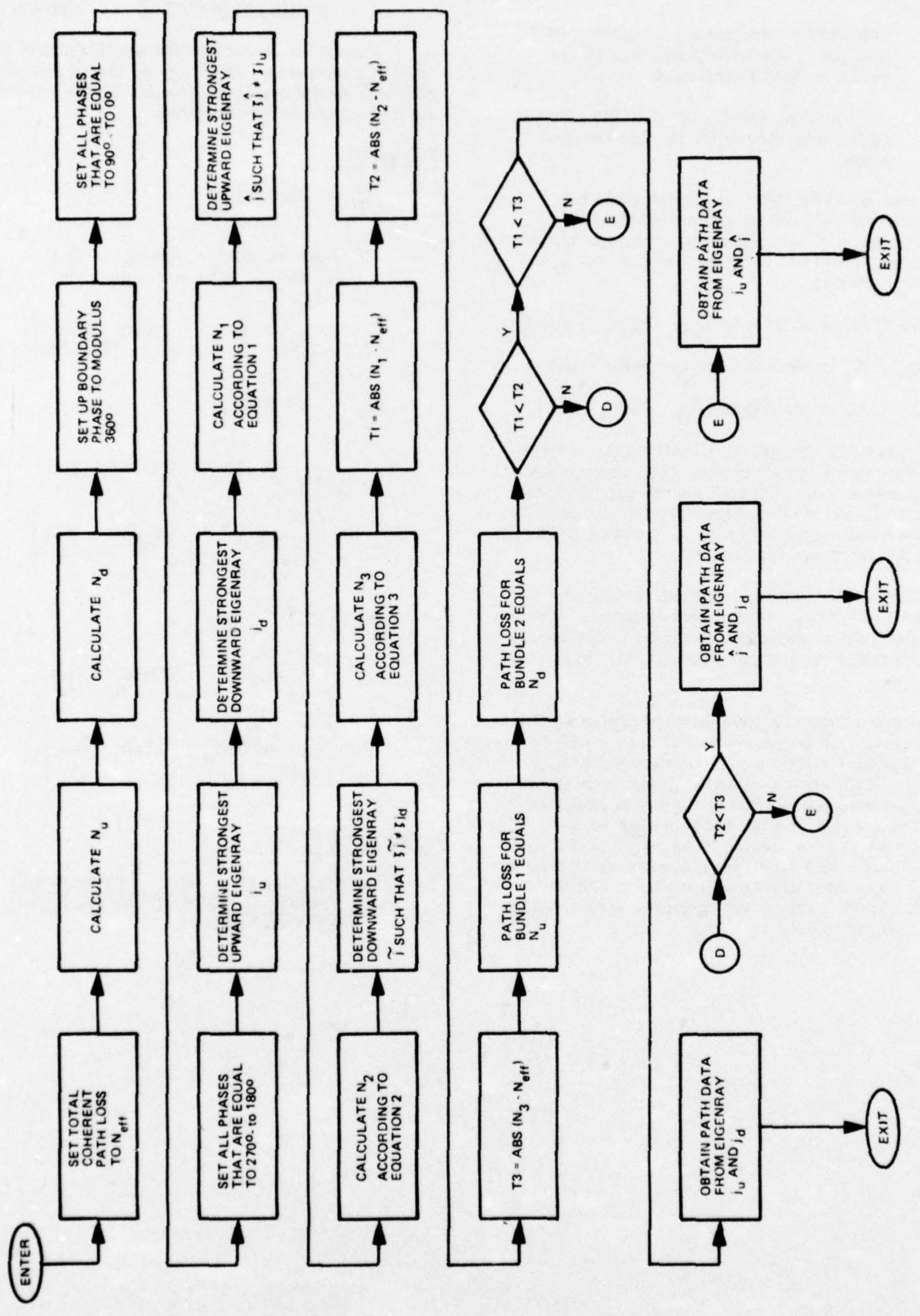

Figure 9. Bundling Algorithm Flow Chart

f. Select the strongest downward eigenray ($j = \tilde{j}$) such that $\zeta_{\tilde{j}} \neq \zeta_{j_d}$

g. Coherently combine the $\tilde{j}$ eigenray path with the j_u eigenray path, N_3, in accordance with Equation 3.

h. Values of N_u and N_d provide the propagation loss values for the two bundled paths.

Associated acoustic information required for simulation/stimulation includes angles and time of arrival and discrete phase information, which are obtained from the eigenray paths by using the following criteria:

(1) If N_1 is closest to N_{eff}: Paths j_u and j_d

(2) If N_2 is closest to N_{eff}: Paths $\hat{j}$ and j_d

(3) If N_3 is closest to N_{eff}: Paths $\tilde{j}$ and j_u.

Figures 10 through 12 illustrate the outputs obtained by using the aforementioned algorithms. The parameters for Figure 8 and 10 are identical, serving to illustrate the higher fidelity obtained by using the bundling algorithms, as opposed to selecting the strongest eigenrays.

Figure 11 illustrates typical results obtained in well-defined interference regions. Once again, use of the bundling algorithms provides excellent correlation with the primary NISSM II output.

For a caustic region typically associated with convergence zones, NISSM II uses a -90 degree phase shift. For the bundling algorithm, once N_u and N_d are calculated, it has been shown that the caustic phase shift is no longer required. Hence, phase information provided for each bundled path is represented by either 0 or 180 degrees to account for the surface boundary phase shifts. To use the aforementioned algorithms within a caustic region, the following step should be included after Step b:

b1. Modify all phase shifts to account for surface boundaries only; delete the caustic phase shift of -90 degrees.

Figure 13 illustrates the application of the caustic correction. Once again, the output of the NISSM II model and that provided by the bundling algorithm are well correlated.

EQUATIONS

$$N_1 = -20.0 \log_{10} \text{ of } \left| 10^{-0.05N_u} \cdot e^{i(2\pi f t_{j_u} + \zeta_{j_u})} + 10^{-0.05N_d} \cdot e^{i(2\pi f t_{j_d} + \zeta_{j_d})} \right| \quad (1)$$

$$N_2 = -20.0 \log_{10} \text{ of } \left| 10^{-0.05N_u} \cdot e^{i(2\pi f t_{\hat{j}} + \zeta_{\hat{j}})} + 10^{-0.05N_d} \cdot e^{i(2\pi f t_{j_d} + \zeta_{j_d})} \right| \quad (2)$$

$$N_3 = -20.0 \log_{10} \text{ of } \left| 10^{-0.05N_u} \cdot e^{i(2\pi f t_{j_u} + \zeta_{j_u})} + 10^{-0.05N_d} \cdot e^{i(2\pi f t_{\tilde{j}} + \zeta_{\tilde{j}})} \right|. \quad (3)$$

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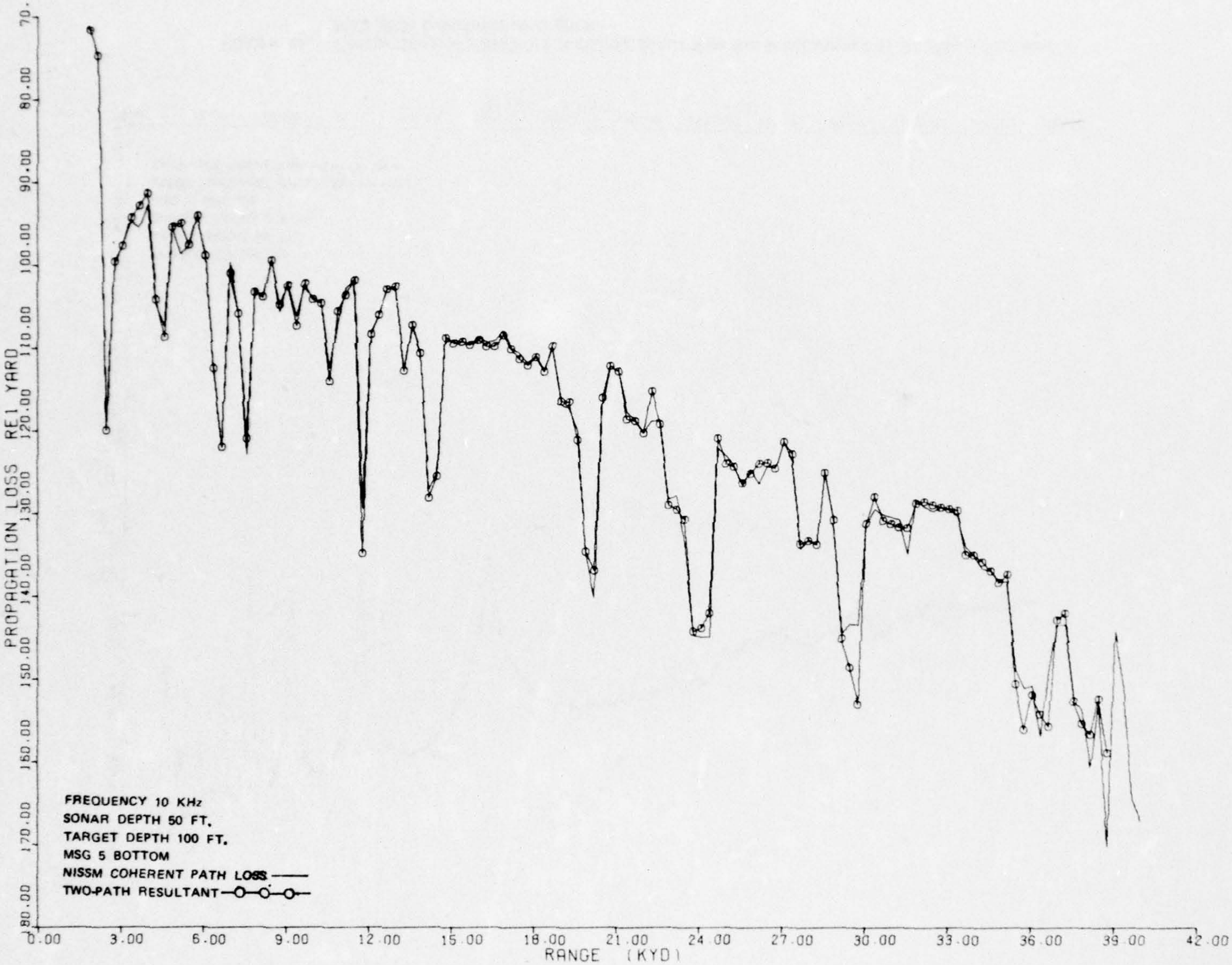

Figure 10. Comparison of NISSM vs Bundling Algorithm for Mediterranean Profile - Summer

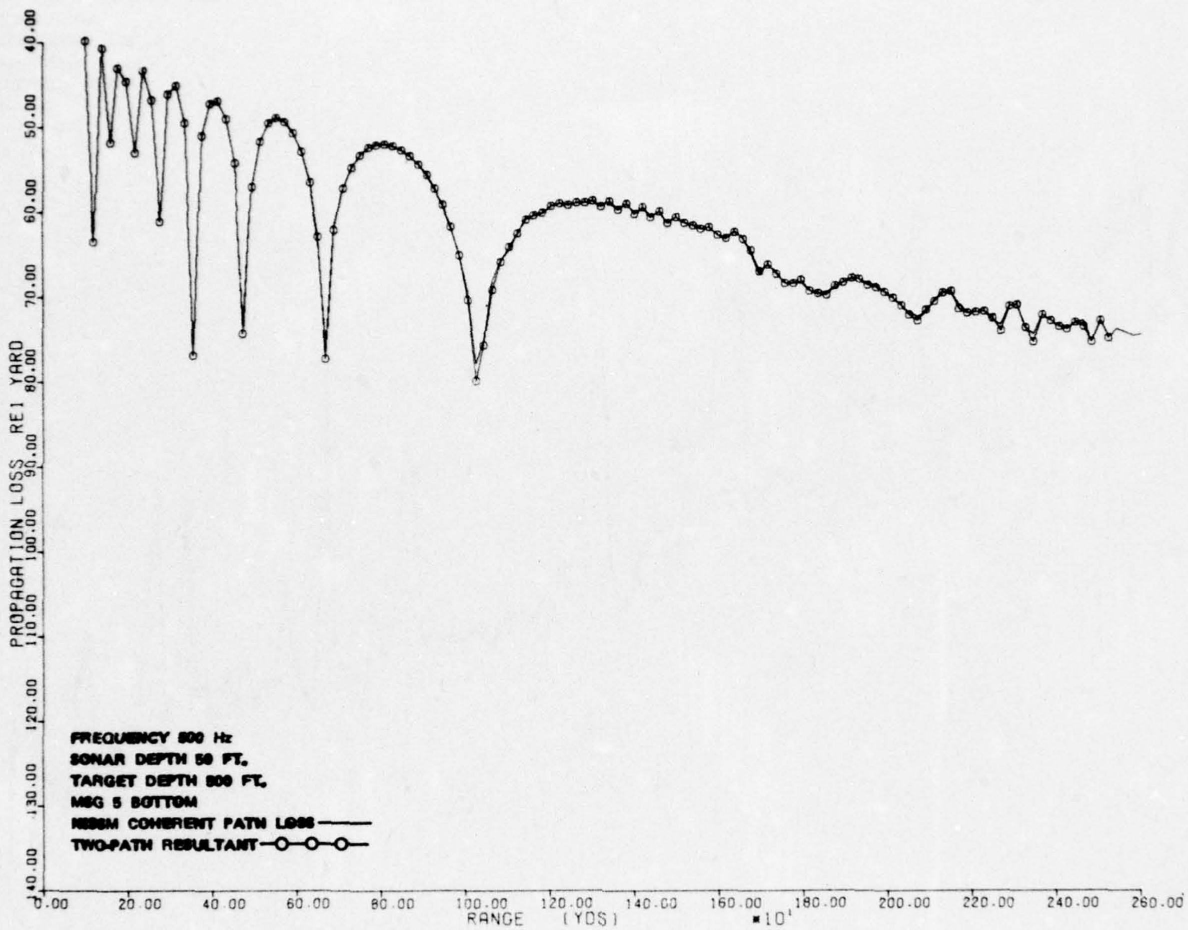

Figure 11. Comparison of NISSM vs Bundling Algorithm for Mediterranean Profile - Summer - Multipath Interference Region

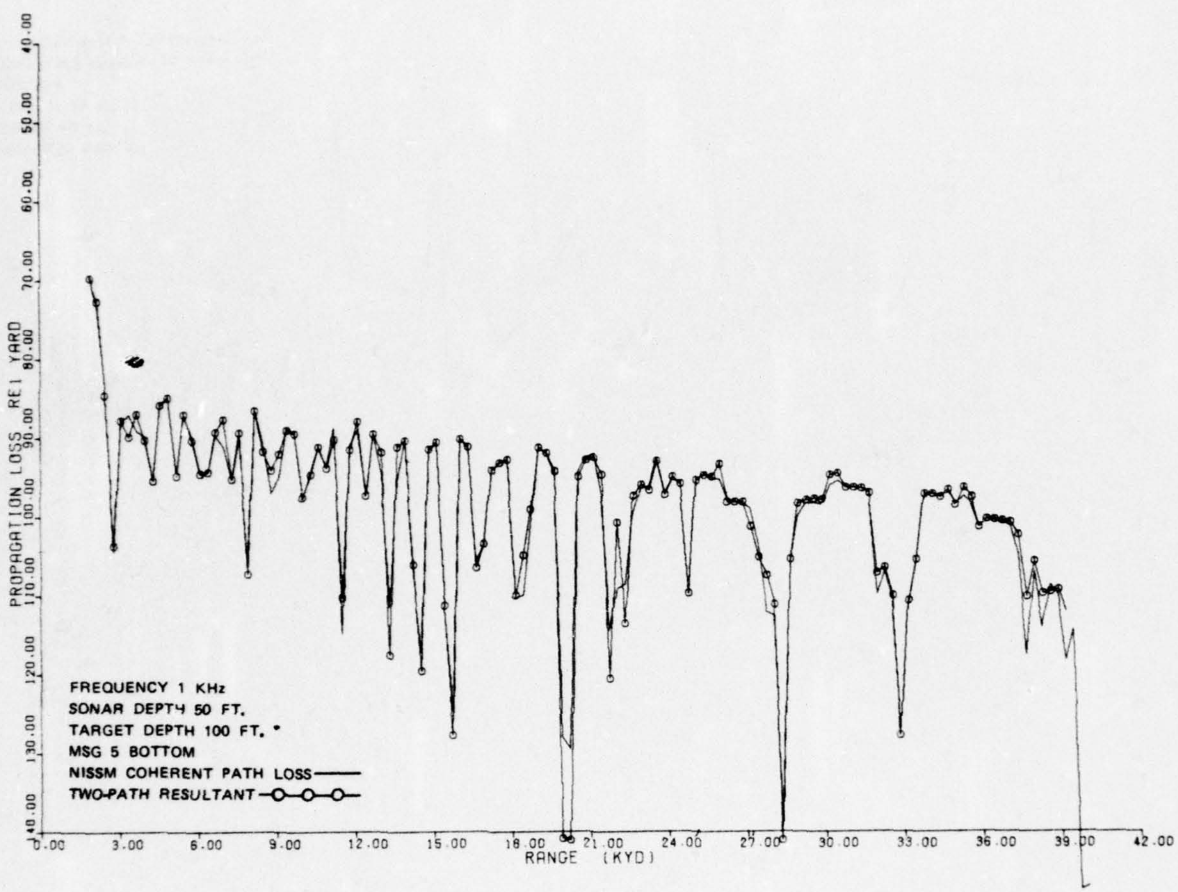

Figure 12. Comparison of NISSM vs Bundling Algorithm for Mediterranean Profile - Summer

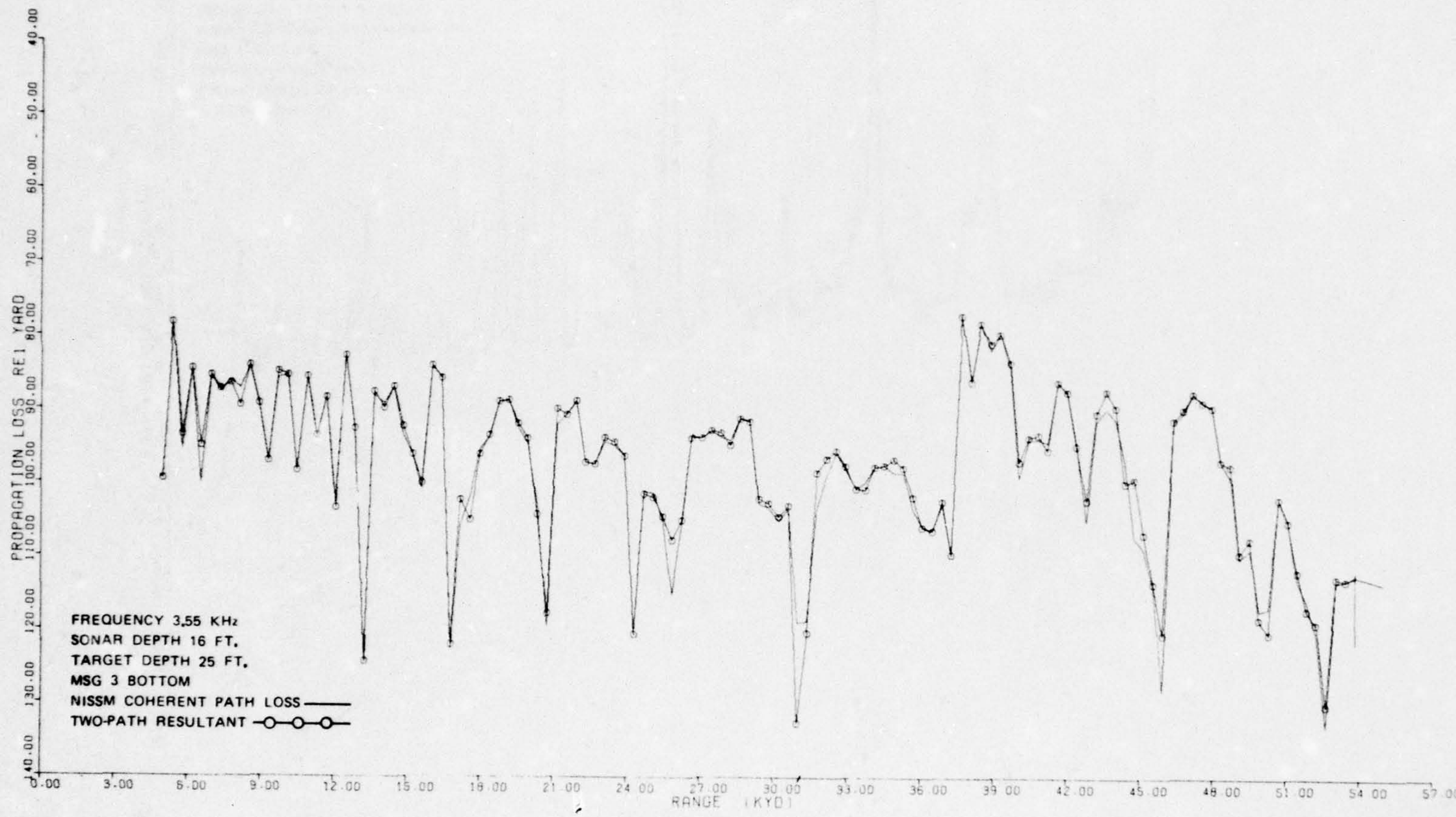

Figure 13. Comparison of NISSM vs Bundling Algorithm for Tyrrhenean Sea - Convergence Zone

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THE SIMULATOR INSTRUCTOR - A READINESS PROBLEM

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BACKGROUND

The increasing pressure to extend utilization of simulator training, the continuing increase in sophistication of weapon systems, and the accelerating application of advanced simulator technology are creating new sets of problems for the simulator training system. Many of these problems are centered on one of the key sub-systems - the instructor. Most of these problems which will be discussed in the following paragraphs, stem from the failure to treat simulation training as a system, and in particular, the failure to adequately structure the role of the instructor and to design the required interface. Thus, while wide-angle visual systems, complex motion platforms and sophisticated CRT's have been added, the functions and interface for the instructor have been largely ignored and the resultant instructor console becomes a victim of design "fall-out." To complicate the problem, the characteristics of the instructor pilot and the operational training concept are also changing significantly.

Feasible solutions which have been advanced, range from one extreme represented by complete automation to the other requiring highly trained and specialized simulator instructors. Neither is currently implementable or acceptable. Yet, little other effort has been expended to resolve the problem.

The dilemma created has parallels in other fields where full scale application of technology, especially computer technology has occurred with almost equivalent disregard for the requirements of the human decision maker. Automated materials handling presents an excellent example. One airline, for example, after installing a sophisticated automated cargo handling system, was forced to fall back and redesign the system - "We had to go back to the time when man, not the machine, was the boss of cargo handling." [4] Perhaps the time has also arrived to return to the concept of the instructor as the "boss" of simulator training.

INSTRUCTOR PILOT STUDY

Recognizing that major changes were occurring in simulator design and that instructor problems were arising, the Human Factors Laboratory of the Naval Training Equipment Center undertook a study of the instructor pilot's role in simulator training with the ultimate goal of defining and designing the required instructor consoles. The effort included a survey of the current role of the instructor pilot (IP) in readiness training, an analysis of instructor functions and the development of instructor console design concepts including the feasibility of modularized and standardized consoles.

The study began with an analysis of a generic simulator training system. Figure 1 illustrates the major subsystems considered, i.e., the student, the simulator, the syllabus, and the instructor. The preliminary analyses were directed to identifying the interface requirements for the instructor subsystem and to developing a structure for the collection of data during the survey of simulator training.

In brief, the results[2] showed that each of the training subsystems generate broad demands on the instructor subsystem.

- The student, e.g., requires briefing, monitoring, demonstration feedback, evaluation, and debriefing.

- The syllabus requires implementation including identification and selection of appropriate mission and performance criteria as well as structuring of simulation parameters and control points.

- The simulator requires initialization and operation, and additional simulation support such as air-traffic control and ground crew functions.

Thus, the instructor subsystem provides the integrating function for the entire training system as well as providing missing simulation models and ancillary functions not performed by the other subsystems. As Caro pointed out, "A training program is the manner in which the well-qualified instructor uses the appropriately designed simulator to establish the clearly defined course content within the skills repertoire of the trainee."[1]

The characteristics of existing subsystems were surveyed. The following paragraphs summarize the results.

SYLLABUS PROBLEMS

The typical simulator flight training syllabus is based on or "borrowed" from the flight syllabus. Thus, it rarely identifies or structures in the required detail those parameters and functions which are not controllable in flight. This is not a trivial

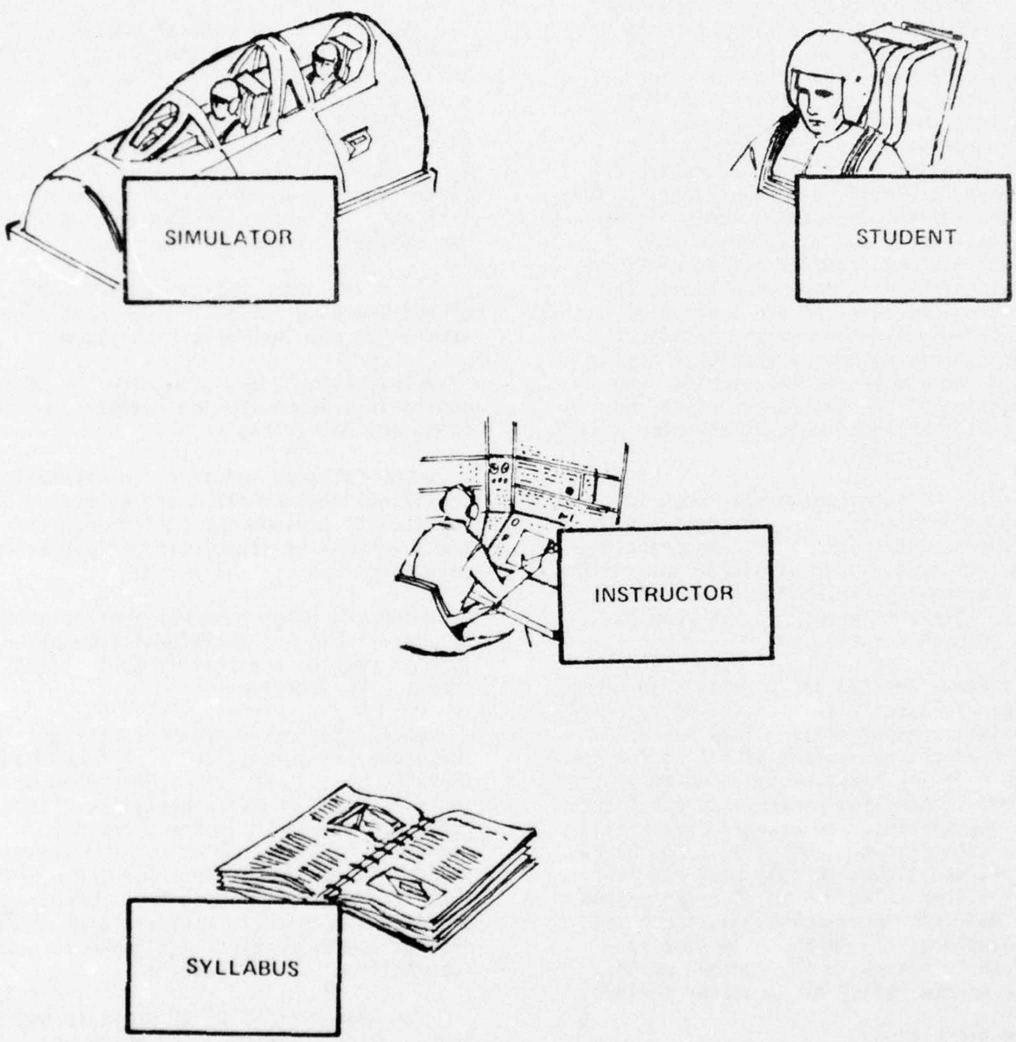

Figure 1. Simulation Training System Components

set and in a modern simulator, for example, includes:

- environmental variables such as winds, temperatures, turbulance, variation
- location variables such as latitude/ longitude, attitude, runways
- radio-navigation aid variables such as type, frequency, identification
- visual variables such as ceiling, visibility, lighting
- malfunctions and emergencies onset, development and resolution
- simulator operating controls such as motion actuation, visual actuation, start, reset
- training controls such as freeze, demonstrate record, replay
- vehicle configuration including fuel, stores
- operational environment including targets and characteristics, jammers

Thus, a modern simulator will contain hundreds of parameters and controls which must be set. While some automation exists, the impact on the instructor is not correspondingly reduced since he must at least verify the configuration. The burden on the instructor is obviously sizeable when the syllabus does not identify or structure the flight training envelope much less the mission scenario and enemy tactics.

INSTRUCTOR CONSOLE PROBLEMS

The instructor consoles in digital operational trainers can be grouped into two types based on vintage. The first generation trainer consoles typified by the F-4J trainer (2F88) can be described in terms of:

- "wraparound" console
- "repeater" cockpit instrument panel
- displays and controls arranged by aircraft system

The consoles were reasonably well human engineered within the constraints involved. In general, they were designed for a two- to three-man operation, at least one of whom is a simulator technician well qualified in manipulation of the complex consoles. Instructor personnel - pilots and naval flight officers - "boss" the training evolution.

The second generation consoles such as the T-2J trainer (2F101) are typified by the extensive use of CRT's and keyboards for all display and control functions. Mechanization has generally involved wide use of both text and pictorial displays. Unfortunately, it appears that the wide capability of graphics displays has led to an instructor console design philosophy of providing a display and a control for any and everything. Thus, any requirement is bound to be satisfied. Unfortunately, this has led to CRT's with hundreds of pages of text, displays, and indexes resulting in a distinct probability that the instructor will fall behind the training evolution in the first minutes of operation.

INSTRUCTOR PROBLEMS

The instructor subsystem in operational trainers presents another set of problems which closes the loop on the dilemma. The study revealed that the role of the instructor and the supporting or assisting role of the technician varies with the nature of the weapon system involved. In single place aircraft systems, the technician generally contributes significantly since the trainer is generally a weapon system trainer. The system itself is complex, and no other instructors are involved. In multiple-crew aircraft, the role appears to vary with mission of the system and the role of the pilot in the system.

Where the pilot is almost exclusively concerned with vehicle control, the IP can and does conduct the simulator training generally on operational flight trainers (OFT) with little if any assistance. Where the pilot is intimately involved in multi-crew system operation, the IP functions as one of several simulator instructors at the console(s) with other instructor(s) and technician(s) assistance. Yet, in general, the instructor consoles are designed alike; i.e., with little consideration for the instructor team composition or functions.

Finally, the IP, almost without exception, is not trained in simulator operation or more importantly, in simulator utilization in support of the syllabus. Very limited on-the-job training is typically provided the IP.

In summary, the typical modern simulator training system in operation can be characterized by:

a. inadequately designed syllabus

b. ineffective interface or console

c. inadequately trained IP

PROBLEM SUMMARY

The problem is multifaceted and interacting. Although unique simulator syllabus development can and should be undertaken, it must consider the interaction with the instructor and the console. The console or interface cannot be well designed until the characteristics of the IP and the syllabus and training objectives have been identified. The instructor cannot be trained until his role is defined. Thus, the problem is a typical systems' engineering problem and as Machol summarized, "Because the problem cannot be adequately formulated until it is well understood, and because it cannot be well understood until it has been more or less solved, the two are inseparable."[3]

Thus, the requirement is for the interactive analysis and trade of performance, constraints, and design alternatives.

INSTRUCTOR DESIGN CONSTRAINTS

The study of the IP in simulator training revealed that, at least in present training operations, the instructor subsystem could be characterized as follows:

a. The simulator IP is a relatively junior flight instructor virtually untrained in simulator operation or utilization.

b. The console is designed for simulation variable control rather than for training functions.

c. Definitive simulation training scenarios are seldom provided.

d. Briefing/debriefing capability is limited.

e. Standard ation of training is minimal.

The picture is not unlike other system designs in which each component is designed independently to different criteria. Yet, tradeoffs and effective designs are feasible to most mixes of console designs and instructor characteristics. For example, if qualified flight instructors are to be utilized with minimal training in simulator operation, then the characteristics of the console and syllabus might be stated as including:

(1) An IP console with maximum similarity to the cockpit to minimize IP training and to take advantage of his already achieved skill in evaluating system performance. There would be little doubt that a qualified pilot could evaluate aircraft condition more rapidly and meaningfully from a duplicate of cockpit displays than he could from alphanumeric readouts on a CRT.

(2) Automated or technician supported simulator initialization and operation.

(3) A general standardized syllabus defined in operational terms for IP use.

(4) A detailed translation of the syllabus in simulation implementation terms for support personnel (or software mechanization).

On the other hand, if highly qualified and trained simulator instructors are to be utilized, a unique and sophisticated instructor console could be implemented with little similarity to the operational cockpit.

Alternative designs depending primarily on instructor characteristics are clearly possible. Unfortunately, the typical present-day simulator incorporates both an instructor console and a syllabus which are not designed to meet instructor requirements.

OVERVIEW

Effective simulator training can only be achieved by considering the simulator as part of a training system which includes the instructor, the syllabus, and the student. Design constraints, especially in terms of instructor characteristics must be identified and reflected in the design of the instructor consoles. Similarly these constraints, along with training objectives must be utilized in the development of the simulation training syllabus if efficient, effective, and standardized training is to be achieved.

The findings reported in the study of the IP's role in simulator training lead to the conclusion that the instructor personnel, at least for the near future, will be operational personnel; i.e., operationally qualified pilots and Naval flight officers. Furthermore, minimal training in simulator utilization will be provided for many reasons including:

a. Simulator training will be "collateral duty" along with flight instruction and other squadron duties.

b. Transfer and rotation of personnel will preclude any extended training program in simulator utilization.

c. Multiple training functions of the instructor; i.e., academics, flight, and simulation will preclude specialization in simulator utilization.

Thus, simulator instructor consoles should be designed for utilization by

operational personnel with a minimum requirement for training in simulator utilization and a maximum utilization of existing IP skills and abilities. These design objectives are readily achievable with existing design technology and methodology.

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ESTABLISHING TRAINING CRITERIA ON AN ECONOMIC BASIS

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INTRODUCTION

The Problem

The training community has toiled for many years in an attempt to establish exactly what is meant by the phrase "training effectiveness." Although no one can precisely define it, the concept of effective training is of interest to psychologists and managers alike. The question is continuously being posed by managers: "is our training program cost-effective?" Subsequently, training psychologists begin expounding on the multitude of factors that comprise the known principles of learning (reinforcement, habit patterns, immediate feedback, etc.). At the end of the discussion, the managers conclude that they know (viscerally) that training is necessary but they recognize that the psychologists cannot convince each other, let alone "laymen." Thus, the schism between the "shrink" and the "bean counter." The goal of the present paper is to develop a quantitative and, more importantly, a communicable framework for establishing training effectiveness criteria that can be used and understood by both the training specialist and the manager.

Training Decisions

In the process of developing a training program, an obvious question relates to which behaviors (tasks) will be trained and which will not. That is, for any nontrivial operator's job, it is impossible to exhaust the possible contingencies that might arise. In fact, humans are often included precisely to utilize their conceptual generalization capabilities. The only point here is that one decision that must be made is whether or not to train on a particular task. To date, there has been no algorithm established to assist in this decision.

A second decision which is an extension of the same issue is, if a task is to be trained, what level of proficiency should be required? That is, what should be the training duration (which the manager translates into dollars). It is well known that the rate of learning exhibits diminishing returns as a function of training time.

A third question, that has become prominent in military training, is related to the complexity (cost) of training devices. As with the relation between learning rate and time, there are diminishing returns of learning rate as the complexity of the training device surpasses a particular level. Figure 1, illustrates the relationship of learning rate and device complexity (cost). The "bean counter" is obviously interested in establishing where the additional cost of training (time and/or devices) is not warranted. This paper will present an approach to establishing the required information necessary to make the above decisions and a quantifiable format of this information.

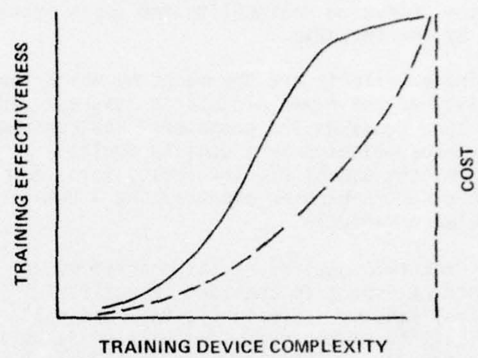

Figure 1. Cost and Training Effectiveness as a Function of Training Device Complexity

The Quality Control Aspect of Training Criteria

Training programs can be viewed as means of increasing the reliability (i.e. quality) of one of the components in the man-machine system. Therefore, the "training criteria" (time, performance levels, etc.) are analogous to the quality levels utilized in industrial quality control schemes. Therefore, the factors that are involved in establishing quality levels in a Bayesion economic analysis model (costs, payoffs, and probabilities) are appropriate to establishing the cost-effectiveness of training criteria on the basis of a Loss Function. The goal of this approach is to determine the out-going level of the trainee on the basis of minimizing total costs that relate to that quality level.

METHODOLOGY

The general approach discussed in this paper involves viewing training as a means of increasing the reliability (quality) of the human operator. The training criterion (outgoing quality) is established within the context of decision theory parameters (costs, payoff, and probabilities).

Increasing Reliability Through Training

Although it is seldom discussed in this context, training is simply a means of increasing the reliability of one of the components in a man-machine system. In the same sense that increasing the quality of any other component (in terms of material or workmanship) increases reliability, the quality of the human component is increased through training. There are both advantages provided by the increased reliability and costs incurred by the increase.

Training criteria are the means by which the quality of the human product is assured. In the same sense as the producers' and consumers' risk are variables in a quality control scheme, the amount of risk (cost) involved with undertraining or overtraining a human is also a variable.

The "natural" quality of the process is an important aspect to consider in quality control schemes. Similarly, the "natural" reliability of the human for various tasks is important in establishing the training criteria. There is an extensive amount of research literature on the topic of human reliability. This information is often "descriptive" of the human (e.g., Askren and Regulinski, 1969; and Beck, Hayman, and Markisohn, 1967); but it also includes information that is "prescriptive" in nature (Feherman and Siegel, 1973; Siegel, Wolf, and Lautman, 1974; and Sontz and Lamb, 1975). These studies have resulted in an extensive methodology for assessing human reliability; however, there is little direct information as to increases in human reliability through training (Goldman and Slattery, 1964). This relationship must be inferred from the reliability data in combination with information about learning.

Learning Rate

The literature on reliability and human performance provides extensive data and a methodology for estimating human performance parameters. That is, the range of the potential "outgoing qualities" for various types of tasks can be, and in some cases has been, established (within rather large bounds). The question remains, however, as to the rate of quality increase (learning) as a function of time. In fact, there is a significant amount of information pertaining to learning rates for both discrete-serial and continuous perceptual-motor tasks (e.g., Fleishman, and Parker, 1962; and Neumann and Ammors, 1957). For various types of tasks, the learning rate versus time function (the learning curve) can be specified with relative confidence. In fact, the stability of the learning curve has resulted in severe difficulties in demonstrating effects due to different "training techniques." That is, for a given task, trainees learn "in spite of the training technique." For the purposes at hand, this is a significant advantage. Figure 2 illustrates the general shape of the learning curve.

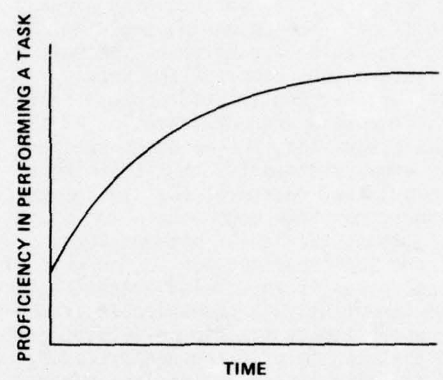

Figure 2. Typical Learning Curve

Information Requirements

As discussed in the previous sections, there is, to a greater or lesser degree, an extensive literature base pertaining to human reliability and learning rate as a function of time. The present section addresses the other information that is required to establish an outgoing quality level of a training program on the basis of economics.

The first (and in the extreme, the most obvious) parameter is the probability that the operator will ever perform the particular task. For example, emergency procedures to handle abnormal situations often occur with a relatively low probability. Intuitively (and pragmatically) there is a low probability of occurrence beyond which training on that task would not be "justified." Similarly, on the other end of the continuum, for

a task that occurs routinely, training could probably be "justified." The point is that (as with the relationship between the probability of a defect and the requirements for a quality control scheme) the existence or extent of training on a task is affected by the probability of that task occurring.

A second set of parameters that is required for an economically based decision is that of costs. There are two general categories of cost. One category involves the costs of training. These costs include personnel costs (trainees, instructors, managers), training equipment procurement costs (from textbooks to complex system simulators), and operation and maintenance costs (including those associated with facilities). Another category of costs that is important in establishing training criteria involves the cost of a failure to perform the operational task. Included in this category are such things as costs due to waste when an operator allows a process to go out of control, equipment damage, and loss of life or personal injury.

Obviously, some of these costs are more easily arrived at than others. For example, the "cost of human life or injury" is potentially very difficult to ascertain. However, in terms of law suit settlements, these numbers are being established. In addition, tacticians have been establishing equally difficult costs in war-game simulations that are used to evaluate a weapon system's effectiveness. The point to be made here is that, although assessing (or at least asserting) costs is often difficult, it is possible. A second point is that "establishing" these costs is not within the technical area of the training specialist and cannot, therefore, be his responsibility. This is analogous to the costs in the economic decision process of establishing outgoing quality levels in any quality assurance situation. It cannot be the quality control specialist's responsibility to determine the costs of "unacceptable" quality.

The last set of parameters that impacts upon training criteria decisions involves the payoffs afforded through training as a function of time. That is, what are the probabilities that the human will "handle" the situation given that the situation does occur. Similarly, how does this probability vary as a function of training time. These questions relate to the previously discussed human reliability estimates and the learning curve. Whereas, the probability of a situation occurring and the costs involved are the responsibility of managers (with the counsel of experts in reliability and economics), this aspect of the information necessary for a decision is within the technical expertise of the training (human performance) specialist. Now that the categories of information have been established, the following section of this paper will address the computation involved in the decision "process."

COMPUTATIONS

The purpose of this section is to present a "first-cut" algorithm that is potentially useful in making training criteria decisions. First, it is necessary to establish the notation that will be used and define the meaning of the parameters.

- P_{occ} - probability that the situation will occur.
- P_o - probability of performing the task without training, given that the situation occurred.
- P_t - probability of performing the task after training time t, given that the situation occurred.
- $K_{\Delta t}$ - cost of a unit of training time.
- K_{occ} - cost of a failure to perform the task.

The increase in the probability of the human to perform a task after training time t is:

$$(P_t - P_o)\,(P_{occ})$$

The pay-off value contributed by the training is:

$$(P_t - P_o)\,(P_{occ})\,(K_{occ})$$

The cost of training for a period of time t is:

$$(K_{\Delta t})\,(t)$$

Therefore, "the break-even point" in terms of the training criterion is when the pay-off value of the training is equal to the cost of the training. That is, when:

$$\frac{(P_t - P_o)\,(P_{occ})\,(K_{occ})}{(K_{\Delta t})\,(t)} = 1.$$

When the left side of this equation is greater than 1, additional training is cost-effective; when it is less than 1, it is not.

Manipulating this equation results in:

$$\frac{(P_t - P_o)}{t} = \frac{(K_{\Delta t})}{(P_{occ})\,(K_{occ})}.$$

As discussed in the previous section, providing the data for the right-hand side of the equation is the responsibility of the combination of manager, reliability expert, and the economist. The information pertaining to the right-hand side is the responsibility of the training specialist.

Recall, from the previous section that the increment in rate of learning is not a linear function of training time. Therefore, the optimization process of the decision involves increasing training time (t) to the point where the equation is satisfied. Figure 3, graphically illustrates this procedure.

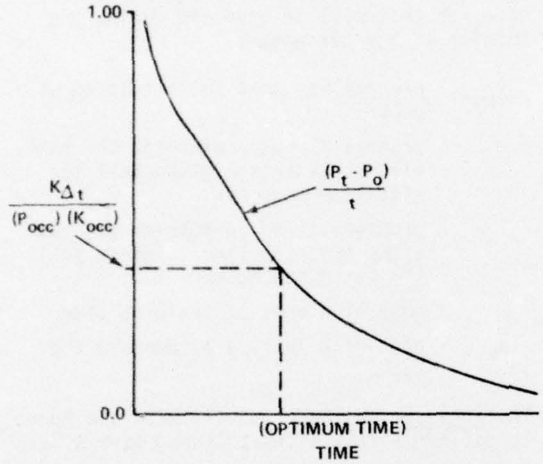

Figure 3. Function Relating Training Decision Parameters

HYPOTHETICAL EXAMPLES

For the purpose of illustrating the method, a simple example will be presented. Assume that a training program is being initiated in a widget factory. There is a particular situation that can lead to a malfunction that approximately one out of twenty operators experience (e.g.,average tenure in the job of 5 years, probability of situation occurring is 0.01 during any particular year). If the situation occurs, the operator must perform a series of steps in a procedure within a short period of time. If he fails, the widget-making machine explodes with a replacement cost of $16,000. The total cost of one unit of training time is $35.00. In addition, assume that the learning rate is approximated by the curve found in the study by Fleishman and Parker (1962). The question is: "How long should the operator be in training?" The parameter values for this example are:

$K_{\Delta t} = 35$; $K_{occ} = 16{,}000$; and $P_{occ} = .05$.

Figure 4 illustrates the function, $P_t - P_o = f(t)$ and Table 1 gives discrete values of $P_i - P_o$, t, and $(P_t - P_o)/t$.

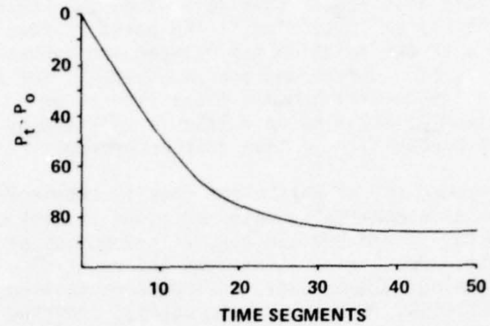

Figure 4. Learning Curve Adapted from Fleishman and Parker (1962)

Table 1

$P_t - P_o$	t	$\frac{P_t - P_o}{t}$
0	0	.00
.25	5	.050
.49	10	.049
.66	15	.044
.76	20	.038
.84	30	.028

The calculation results in:

$$\frac{K_{\Delta t}}{(K_{occ})\ (P_{occ})} = .0438.$$

Therefore, it can be determined from the table that approximately 15 time units of training is optimal.

A second example, in a different context, is an overcoat manufacturing factory in which there is a training program for seamstresses. In this case, the P_{occ} is the probability that the customer will decide upon buying the coat on the basis of the sewing (as opposed to the material or design). The K_{occ} is the lost revenue if the customer does not by the coat. In this case, however, the P_t is the probability that the customer will accept the coat, given that the sewing is one of his decision points. Through training, the P_t value increases as in any other learning situation. Given the required cost

data, probabilities, and learning curve, the extent of training that is cost-effective can be determined.

The purpose of the present paper, and the examples given, is to demonstrate the feasibility of approaching training requirements in terms of decision theory parameters. The next section discusses the next steps in refining this approach.

NEXT STEPS

An integral part of the approach described in this paper is the use of the learning curve characteristics in determining training criteria. It was stated earlier that we have an extensive amount of information pertaining to the shape of the learning curve for many tasks. However, what is needed for this approach (as well as many other aspects of human performance) is a descriptive "taxonomy of tasks" that vary in their learning characteristics. This taxonomy could be used by training learning specialists to estimate the function $P = f(t)$ for the tasks that make up their particular operational job. There have been selected efforts in the area of task taxonomy (e.g. Miller, 1971). In fact, Meister and Mills (1971) and Mills, Bachert, and Hatfield (1975) have categorized tasks in terms of human reliability. Swain (1963, 1974) has also demonstrated this possibility. Although this work does not provide learning curve information, it does serve to set the boundaries in terms of human performance reliability.

The actual calculations required by this methodology could be significantly simplified by applying an appropriate transformation to the curve that would result in a linear relationship. For example, a logarithmic transformation is the obvious starting point for this type of effort.

In addition to increasing the confidence in the learning data and simplifying the computation requirements, a major "next step" is to determine the sensitivity of the various parameters. This type of analysis will allow one to allocate his time appropriately in terms of refining the information to which the cost-effectiveness is most sensitive.

IMPLICATIONS OF THE METHODOLOGY

One of the more interesting implications of the proposed methodology is that it illustrates the absurdity of the "perfect mastery" approach on a cost-effectiveness basis. That is, on the basis of costs and payoffs, it is the rate of learning as a function of time that is the important metric. The appropriate criterion for terminating training for a particular individual is when his increased proficiency gain per unit time (i.e.,dollars) is less than the payoff contributed to operational success. This approach is compatible with the techniques of Computer Managed Instruction (or adaptive training in perceptual-motor skill training) in that the rate of proficiency increase is accessible. The point is that an individual's present proficiency is not the only criterion variable; it is also important to evaluate his rate of advancement and subsequently estimate his potential for further advancement.

Another important implication of this methodology is the categorization of the types of information necessary to make valid training system design decisions and the assignment of responsibilities for the various information. Decisions relative to training criteria are the joint responsibility of operational personnel, managers, and training specialists.

The problems of establishing training criteria are very complex; however, there must be a framework from which to start if progress is to be made. The present paper discusses the applicability of techniques presently developed in the areas of quality assurance, training technology, and decision theory to the problem of establishing cost-effective training criteria. The types of data required, and the appropriate responsibilities for those data are discussed. There is no apparent reason why the cost-effectiveness of training cannot be established through the same methods as have been used for other systems for many years and with significant methodological advances.

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DD-963 CLASS DESTROYER ENGINEERING CONTROL AND SURVEILLANCE SYSTEM TRAINER

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SILVER SPRING OPERATION

The Navy requires trained crews for operation and maintenance of the DD-963 Destroyer Engineering Control and Surveillance System (ECSS). Engineering crew training onboard ship is not optimum in terms of personnel safety, equipment readiness requirements, fuel conservation, environmental considerations, manpower assignment, and other logistical considerations. The new and highly automated design of the DD-963 Class destroyer and the limited availability of these ships for training engineering crews emphasize the use of an alternative training approach. The DD-963 Class destroyer ECSS trainer provides effective operation and maintenance training in a wide spectrum of situations that cannot be practically performed under normal operations on board ship. Capabilities of software simulation models create a trainer that can accurately duplicate ship conditions from cold steel to cruising. With a versatile training device of this type, ECSS crews -- through practical experience in operations and maintenance -- can be thoroughly prepared for virtually every aspect of their particular assignments onboard ship.

The systems simulated in the trainer accurately recreate ship performance and generate signals to "stimulate" actual shipboard equipment, namely:

- Electric Plant Control Equipment (EPCE)
- Propulsion and Auxiliary Machinery Control Equipment (PAMCE)
- Propulsion and Auxiliary Machinery Information System Equipment (PAMISE)
- Propulsion Local Operating Equipment (PLOE)

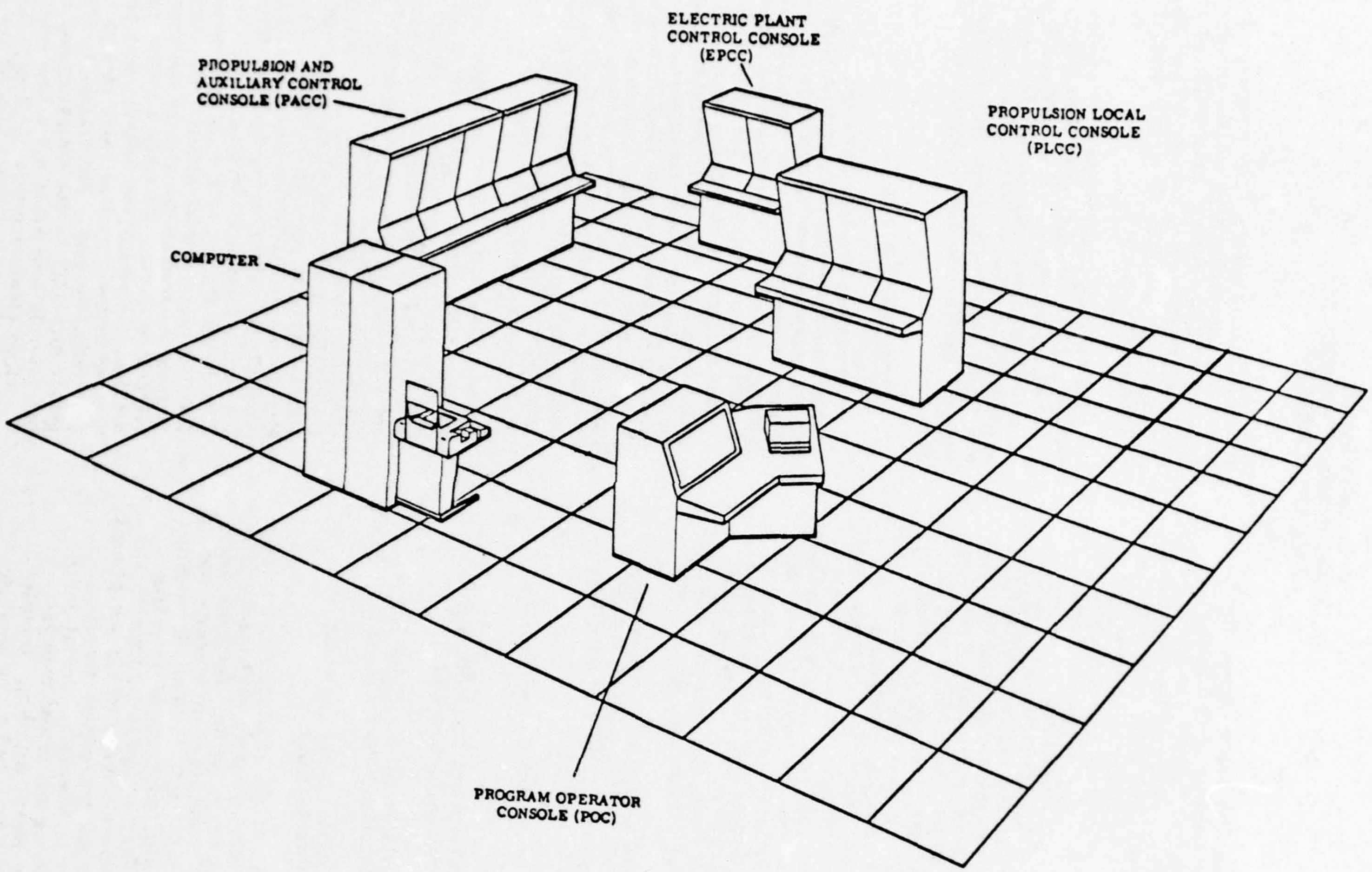
The heart of the simulator/trainer is a medium-capacity high-speed minicomputer with 28K of 16-bit memory words. Software models residing and executing in-core memory communicate with the actual shipboard consoles through two distinct types of interface equipment. Analog signals (-10 vdc to +10 vdc) and discrete signals (0 vdc and 28 vdc) are received and transmitted through a standard hybrid interface. Serial information is fed to and tapped from the interconsole serial data bus. Console alteration has been kept at an absolute minimum to ensure training accuracy and to maintain student safety. For example, console requirements for high voltage current were converted to accept standard analog signals for obvious safety reasons. This type of hardware is suitable for either simulation or stimulation approach.

The consoles used on the ECSS trainer are provided by the Navy from their operations equipment stores. It is through these consoles, configured exactly as their actual shipboard counterparts, that ships' systems are "stimulated" to make the training environment identical to conditions on the real ship.

Operational Training

The trainee develops operating skills through hands-on experience in both routine and emergency engineering procedures. The student is familiarized with the positioning and function of the controls and indicators of each trainer console -- the similarity between trainer and ship being emphasized (see figure 1). This familiarization process could not feasibly be accomplished on an actual ship because of the level of complexity of operating modes and because of the sheer quantity of components on each panel. For example, the Propulsion and Auxiliary Control Console (part of PAMCE) alone includes some 1,000 discrete indicators (alarms/status) and 400 switches.

The principal area of procedures training centers on the control and monitoring of the ship's propulsion gas turbines. Control and monitoring is handled from the Propulsion and Auxiliary Control Console and from the Propulsion Local Control Console (part of PLOE). Start/stop procedures for the gas turbines are drilled in all control modes, manual, manual-initiate, and auto-initiate. In addition to normal start/stop procedures, emergency stops, false starts, internal fires, and module fires are simulated. This familiarizes the student with such occurrences and drills proper remedial action. The simulated propulsion turbines can also be operated at all cruise speeds. To reach a cruise configuration, the propulsion turbines must be coupled to the propeller shaft through the main reduction gear. The trainee is diligently exercised in the reduction-gear clutch and power-turbine brake operations necessary to safely accomplish this coupling. This could simply involve one action if the auto-



ECSS Training Device (DD-963 Class)

initiate mode is selected, or it could involve several brake releases and clutch engagements to achieve a full-power or split-plant configuration.

Other training areas include monitoring/controlling of the gas turbine generators from the Electric Plant Control Console (part of the EPCE). In addition to normal start/stop procedures, trainees learn electric bus-power configuring, automatic- and manual-load shedding, generator paralleling, and bus-loading. The interaction between shore power and ship power is another basic simulation. This familiarizes the trainee with the capabilities of shore power operation and teaches procedures for paralleling generators to shore power. Special features have been incorporated into the simulation program as a result of data received from builder's trials. One such addition is the capability to break a generator shaft from the control console if the proper conditions exist. This is surely an important training item when one considers the danger to human life and the high cost of material replacement of such an action on board the real ship.

Interconsole propulsion information is transmitted via the Engine Order Telegraph (EOT) system. In automatic-throttle mode, the EOT system transmits standard orders (Flank 3, Flank 2, Flank 1, Full, Standard, Ahead 2/3, Ahead 1/3, Stop, etc.) to the appropriate station in control. In manual-throttle mode, the EOT system transmits commanded shaft RPM and propeller pitch. The instructor in the simulated bridge control station communicates plant mode requirements (full power, split plant, secure), in addition to station-in-control commands (pilot house, central control station), to the Propulsion Auxiliary Control Console via the EOT system. All of these operations require exacting care in initiating and acknowledging procedures for errorless communication.

Vital auxiliary systems -- such as fuel oil, lube oil, controllable-reversible pitch (CRP) propeller, and bleed air systems -- are simulated. Procedures for fuel and lube pump operation and alignment are drilled in all operating modes (A-lead, B-lead, and manual). Valve alignment requirements are simulated in the bleed air system to instruct proper valve positioning for various conditions -- low and high pressure starter air (propulsion turbines and generator turbines), masker air (used to create a laminar bubble screen beneath each engine room to attenuate ship radiated noise), prairie air (used to reduce propeller noise), and air for anti-icing (used to warm intake air to prevent condensed water on the demisters from freezing). Since the shafts in the DD-963 Class destroyer rotate in a unidirectional manner, the direction of ship motion is dependent on propeller pitch.

Because of the obvious importance of the CRP propeller system, students are thoroughly exercised in propeller pitch control. Non-vital auxiliary systems, such as the ship's service air system, high pressure air system, waste heat boilers, distillation, and sewage system, are also simulated. Even though these systems do not have extensive controls from the Propulsion Local Control Console or the Propulsion and Auxiliary Control Console, normal operations can be verified and corrective procedures can be reviewed for emergency situations.

Operation of the Propulsion and Auxiliary Machinery Information System Equipment (PAMISE) is another important training area. The PAMISE is responsible for gathering information shipwide from the PAMCE, PLOE, and EPCE, and then processing this data in the Central Information System Equipment (CISE) computer. This information is made available to console operators via the demand display indicators located throughout the consoles. An operator can monitor hundreds of ship parameters by simply dialing an appropriate address. The student learns to program the CISE computer, and he becomes proficient in computer peripheral operation (bell logger, alarm logger, and tape reader).

Since no piece of equipment can be expected to function perfectly at all times, the ECSS trainer also provides for practice in problem identification and resolution.

The instructor can input malfunctions affecting almost every aspect of ship performance. These malfunctions simulate normal operating problems that drill the trainee in recognizing trouble and reacting to emergency operations. Some malfunctions are terminal -- that is, not correctable by the console operator; others can be circumvented if the trainee takes proper actions.

One typical "trainee-correctable" malfunction is loss of low pressure air for starting. The result is that high pressure start air is required or the instructor can initiate malfunction of the fuel oil heater to prevent warm fuel from being delivered to the propulsion turbines. The trainee, realizing the situation, learns to activate the cold-fuel override switch for emergency starting. Lube or fuel pump failures prompt the student to start backup activation. CRP propeller pump failure requires shaft pump backup. Loss of generator turbine power requires an electric load change until the system can be properly reconfigured. Gas turbine generator low frequency or low voltage malfunctions require appropriate adjustments to correct the condition.

A typical terminal malfunction is the lube oil fuel oil strainer differential pressure high alarm. The student (as console

operator) learns to remedy the situation by contacting the instructor (as local operator) ordering a filter change. With the insertion of a journal-bearing temperature high malfunction or a thrust-bearing temperature high malfunction, the student realizes that lube oil is not being supplied in proper quantities. This requires bringing the shaft to a stop to reduce further damage and ordering repairs. These types of simulated emergency conditions cannot practically or safely be created onboard ship.

Maintenance Training

In addition to training in operating procedures, the ECSS trainer provides the student with hands-on experience in maintenance of actual shipboard equipment. Trainees become intimately familiar with all components of the EPCE, PAMCE, PAMISE, and PLOE.

To develop combat-ready skills, students are drilled in rapid fault isolation. This may be as simple as locating and replacing a malfunctioning printed circuit card, or it could involve tracing signals from point of console entry to point of use or display. Printed circuit-card calibration is presented to sharpen skills in standard routine maintenance. This requires removing particular cards from the console, positioning them in proper tests slots, and performing the appropriate test. The majority of information transmitted between consoles is in serial format. Monitoring this information with an oscilloscope, locating faults, verifying content, and checking voting logic, are all tasks which the student learns for this serial data bus.

Other maintenance areas involve nonelectrical components. The student learns to assemble and disassemble such items as the integrated throttles, power level angle (PLA) and pitch quadrants, power supplies, and the like. The instructor can simulate hardware malfunctions in the equipment -- for example, inserting a bad connector, a bad card, or shorting two pins together. Since the training device gets more intense usage than does the actual shipboard equipment, repair of unplanned problems constitute another important aspect of training. This type of "troubleshooting" learning is excellent preparation for ship duty.

As the first simulator/trainer of a gas powered turbine ship, the DD-963 Class Destroyer ECSS trainer provides an ideal training environment for maintenance of the actual shipboard equipment. The first delivered unit is currently located and operational at the Great Lakes Naval Training Center where it is utilized approximately 22 hours per day. This utilization has produced 200 operator personnel and 50 maintenance personnel during the first year of operation.

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MR. H. C. ROBINSON is a principal engineer with The Singer Company, Link Division, Silver Spring Operation. He is currently engaged in the design and programming of digital models simulating the propulsion plant systems of a DD-963 Class destroyer. As part of an ongoing in-house investigation, he is performing a study that involves the analysis of transfer of function efforts to develop a technique to accurately simulate digitally, analog circuits. He holds the Bachelor's degree in applied mathematics from Johns Hopkins University.

PAPERS PUBLISHED, BUT NOT PRESENTED

THE VOICE DATA COLLECTION PROGRAM
A GENERALIZED RESEARCH TOOL FOR STUDIES IN SPEECH RECOGNITION

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INTRODUCTION

The technology of machine speech understanding, integrated with advanced instructional technology, has demonstrated the capability to automate training for tasks which are characterized by the use of restricted, stylized speech. Such a training system for the GCA Controller has been described at NTEC/Industry Conferences in 1974 and 1975.[1,2] This paper discusses the development since that time of a more generalized laboratory research system designed to support speech recognition studies for evaluation of essentially any vocabulary set. Moreover, the program provides the experimenter with sufficient flexibility to investigate training the student on the vocabulary itself; that is, the critical task of teaching proper phraseology to the student.

BACKGROUND

The advantages of automated adaptive instruction are well known to the training community. Tasks requiring verbal commands and instructions had, until recently, been unamenable to these automated training techniques. Performance in speech-based tasks was traditionally measured by subjective instructor ratings. With the advent of the speech recognition capability, however, an individualized, self-pacing, automated training system for these tasks (now including objective performance measurement) became feasible.

The Naval Air Systems Command has supported the Naval Training Equipment Center's (NAVTRAEQUIPCEN) Human Factors Laboratory in efforts to establish design guidelines for such speech understanding-based systems. Indeed, the basic feasibility of these systems was demonstrated in a NAVTRAEQUIPCEN laboratory version of a Ground Controlled Approach Controller Training System (GCA-CTS) developed under contract with Logicon, Inc.[3,4]

LABORATORY R&D, AND THE VOICE DATA COLLECTION PROGRAM

Tasks such as those of the Landing Signal Officer, Air Intercept Controller, and Ship Conning Officer would also appear amenable to a speech understanding-based automated training system. Future R&D should proceed to address these new areas. The GCA Controller has served as a test application; now other vocabularies (applications) must be studied.

Furthermore, the problem of training the student in correct pronunciation and use of the radio terminology, operational brevity code, "standard commands," etc. is itself a subject for study. At least a basic knowledge of the relevant vocabulary is required prior to training for the task which employs the phraseology. R&D efforts can be wisely directed along these lines as well.

Finally, experience with the laboratory GCA-CTS has highlighted certain risk areas associated with the recognition of some phrases. Further R&D analysis of these areas with other vocabularies can support the definition of future training programs, identify problem areas early in the development cycle, and in general support the establishment of design guidelines.

Aware of each of these requirements, NAVTRAEQUIPCEN has supported the development of a highly flexible laboratory research tool called the Voice Data Collection (VDC) program. The VDC program provides the framework around which the researcher can:

a. Define vocabulary phrases associated with essentially any application.

b. Preprogram the presentation of phrases or groups of phrases to the speaker via text, graphics, and/or computer synthesized speech, resulting in an effective environment in which to learn the vocabulary phrases.

c. Test the ability of existing hardware/software algorithms to recognize these phrases, and extract hardcopy data on recognition reliability, correlation scores, and potential system confusions.

As such, the VDC program specifically addresses the three areas previously identified as possible directions of future R&D. The remaining sections of this paper are a brief description of these aspects of the VDC program. A more complete explanation of VDC functions and user capabilities is available in the references.[4]

VOCABULARY DEFINITION

The experimenter's capability to easily define the vocabulary set for investigation is provided via an off-line program which builds a disk file via a dialog with the user on the system teletypewriter. The program will accept the specification of 63 words or phrases in each file. Each of these 63 items is defined by giving:

a. The expected duration of the phrase; e.g., 800 milliseconds for "on glidepath." This datum is later used to (optionally) determine that the student is grossly mispronouncing or garbling the phrase.

b. An alphanumeric text sequence to be associated with the phrase. These data may simply represent the English text of the phrase or a specially defined code useful to an online program.

c. A phonetic text sequence to be associated with the phrase. Again, this may be the English pronunciation of the phrase or some other aural cue or response useful in the online environment.

d. A syntax structure. Associated with the VDC program is a rudimentary syntactical processor which enables the concatenation of phrases within the vocabulary list. For example, "assigned heading" must be followed by three digits. This specification is defined by the syntax structure associated with "assigned heading." Table 1 briefly describes the syntax options available.

In addition to its file creation capability, the off-line vocabulary definition program enables the experimenter to edit the disk file and generate hardcopy reports.

VOCABULARY PRESENTATION, TRAINING, AND VALIDATION

Readers familiar with the GCA-CTS efforts will recall that a necessary process is the extraction of voice characteristics of each potential user. In the early system, computer core restrictions necessitated a simple serial presentation of each individual vocabulary item. The phrase was typed onto the system teletypewriter, and the student was prompted to repeat the phrase the requisite number of times. The system collected data on the student's vocal characteristics, generated the necessary reference patterns, and moved on to the next vocabulary item.[2] Unfortunately, however, the accuracy of the recognition functions of the speech understanding subsystem (SUS) seemed to be directly related to the similarity between the student's voicing of a phrase when "configuring the recognition system" and during regular (GCA controlling) operation. It was difficult to achieve this vocal similarity using the scheme described above.

Also, during the early GCA-CTS efforts it was quickly realized that this "machine training" time — which was originally required only because of the necessity for collecting the speech reference data — could also be effectively utilized as "student training" time — to give exposure in the correct pronunciation and usage of the GCA vocabulary. The limitations of serial repetitions and individual phrases, however, severely hampered the exploitation of this dual mode.

In the VDC program, the experimenter is given complete flexibility in constructing (online or off-line) sequential presentations of multiphrase combinations. Additionally, the experimenter may associate a variety of cues with these phrases via the alphanumeric and phonetic texts in the vocabulary definition file. Furthermore, the presentations can be done independently, in combination with the reference data extraction process, or in combination with the recognition processes. Taken together, these capabilities provide the researcher with complete freedom in devising a uniquely tailored program which:

a. Allows the student to become acquainted with an unfamiliar vocabulary.

b. Transparently collects reference data on the vocabulary item spoken in a realistic sequence.

c. Transparently validates the accuracy of the reference data by attempting to recognize the phrase.

In short, a system can be quickly and easily developed which, from the student's perspective, is teaching him when and how to speak the vocabulary phrases, and, from the experimenter's perspective, is collecting data on the speech recognition and vocabulary training functions. A significant improvement in the quality (accuracy) of the extracted speech reference data is also achieved.

These presentation, training, and validation functions of the VDC program are facilitated by an easy and simple interface between the researcher and the software. Disk files and the presentation devices are named during a sign-on dialog with the system. The functional flow is directed via a command file created off-line, or by entering commands online via a named input device. Examples of these functional commands (regardless of their source) are given in Table 2.

If, during the validation mode of VDC program operation, the user does not specify

TABLE 1. VDC SYNTAX OPTIONS

Code	Definition	Examples*
1	Complete phrase	"execute missed approach"
2	Special word†	"zero," "one," "two," ... "point," "oh"
3	One of N phrases can precede this phrase	"above glidepath ... coming down"; "coming down"
4	One of N phrases can follow this phrase	"above glidepath ... coming down"; "above glidepath"
5.	One of N phrases must procede this phrase	"time to intercept ... track bravo"; "range and bearing ... track bravo"
6	One of N phrases must follow this phrase	"time to intercept ... track bravo"; "time to intercept ... track alpha"
7	N special words can precede this phrase	"7 ... aircraft"; "aircraft"
8	N special words can follow this phrase	"turn left ... 0 ... 1 ... 0"; "turn left"
9	N special words must precede this phrase	"6 ... miles from touchdown"; "4 ... miles from touchdown"
10	N special words must follow this phrase	"assigned heading ... 0 ... 1 ... 0"; "assigned heading ... 0 ... 1 ... 5"

†Special words are vocabulary items which:

1. may stand alone, and/or
2. may appear in a series, and/or
3. may precede a phrase, and/or
4. may follow a phrase.

*Phrases being defined are underscored. Other phrases provide context to explain the syntax.

TABLE 2. VDC FUNCTIONAL COMMANDS

Mode or File Type	Command	No. Arguments	Example	Meaning
"Presentation and Training"	P	1 – 12	"P 14"	Present phrase 14.
			"P 13, 14, 15"	Present multiphrase from concatenated phrases 13, 14, and 15.
	B	1	"B 0"	Begin collecting voice patterns for all phrases.
			"B 10"	Begin collecting voice patterns for phrase 10.
	S	1	"S 0"	Stop collecting voice patterns for all phrases.
			"S 10"	Stop collecting voice patterns for phrase 10.
	T	None	"T"	Terminate presentation function.
"Validation"	P	As above	As above	As above.
	A	None	"A"	Print all statistical data.
	S	None	"S"	Print summary statistical data.
	T	As above	As above	Terminate validation function.

either a command file or other input device, the system will (obviously) not present phrases to the student but rather will "echo" the phrases which it recognizes. The syntax structure defined earlier, together with some rather sophisticated logic, is used to concatenate phrases in this submode.

RECOGNITION ACCURACY AND DATA COLLECTION

An important aspect of the VDC program – especially when considered as a laboratory investigation tool – is its ability to easily and quickly assess the recognition reliability of the hardware/software system and identify misrecognized or confused phrases. Very often, once these risk areas are delineated, the eventual training system can be designed and implemented to support the recognition processes,* and/or minimize the impact of the recognition mistakes.

The results of the laboratory evaluations of the GCA-CTS, for example, have indicated that recognition confusions tend to occur between similar messages for the computer just as they do for humans, as, for example, the phrases "slightly above glidepath" and "slightly below glidepath." For some talkers, the plosive "buh" sound in both phrases tends to obliterate the other differences, particularly if the above/below portion carries unnatural emphasis, and thus the two can be confused. But consider the typical glidepath position error made by a student controller. He is not likely to say "slightly above" when he means slightly below. The more common mistake is failure to distinguish between adjoining zones; for example, by saying "slightly below" when the aircraft is actually below. In the latest GCA-CTS programs, delivered in May, 1976, the Performance Measurement Subsystem, in communion with the SUS, is able to resolve these recognition errors, resulting in <u>understanding</u> (as opposed to recognition) accuracies approaching 100 percent.

The real point to be made here is that, when typical recognition confusions are known, the system can often be designed to tolerate them. The VDC program enables the researcher to identify these problem areas very early in the analysis and definition phase, resulting in greater visibility going into the design phase.

Figure 1 demonstrates a portion of the hardcopy data available from the VDC program. The printout includes a header which provides identifying information followed by each prompted (presented) phrase and by the recognized phrase. Phrases which were misrecognized are flagged with an "*." Phrases that are recognized with low confidence are noted with an "@." Critical recognition parameters are saved for reference, and two overall phrase accuracy figures are calculated: for all phrases and excluding low confidence phrases. If requested by the user, the program will provide more detailed "internal" data collected during the recognition process. This information is particularly helpful to determine specifically <u>which</u> phrases are being confused, the degree of <u>the</u> confusion, and the effects of the various recognition parameters.

(In the "echo" mode described earlier, the <u>comparative</u> data shown in the figure <u>cannot be calculated</u> since the program has no <u>a priori</u> information on which phrases the <u>student</u> is speaking; i.e., no phrases are prompted. The VDC program will, nevertheless, save recognized phrases as well as the associated internal data.)

USE OF VDC IN THE TOTAL TRAINING PROGRAM

Though primarily a research tool, the VDC program is capable of supporting the laboratory task training programs as well. Indeed, the VDC concept was originally intended as a replacement for specific elements of the earlier GCA training system software, albeit with increased emphasis on vocabulary independence. By coupling the VDC and the latest GCA-CTS, together with the DEC display group and PDP-9 computer, the following experimental training scenario has been achieved for the GCA application.

A new student is signed into the system. He receives an audio/visual presentation of the GCA PAR vocabulary via the voice generation unit and graphics display. Via "show-and-tell," the student is instructed in the proper phrases for each radar pip position. The student participates in a follow-after-me mode in which he repeats GCA commands after an appropriate audio/visual cue. As he becomes familiar with the phraseology, the instructor quietly informs the system to start collecting voice data for specified phrases. The student continues this process, always being prompted as to the correct phrase for each situation. He garbles a phrase, but the system forces a repeat. The instructor, finally satisfied with the student's progress, commands the system to generate reference data based upon the information collected thus far.

The student returns later to practice more approaches. At first, he is still prompted by the system. The instructor commands a report on recognition accuracy. "Slightly above glidepath" is being confused

*Indeed, this is one of the distinctions between a speech understanding system and speech recognition. Understanding utilizes contextual and other cues to support the recognition algorithms.

VDC SUMMARY DATA

```
NAME:  GRADY, MIKE                      DATE:  5/31/76
VOCAB LIST FILE:  VLG:GCACTS.VL         VOCAB LIST NAME:  GCA-CTS VOCABULARY REV 01
VOICE DATA FILE:  DP1:GRADY.VD          VOICE DATA DATE:  5/31/76

**********************************************************************************

PHRASE #:   1
  P: SLIGHTLY ABOVE GLIDEPATH
 @R: SLIGHTLY ABOVE GLIDEPATH

PHRASE #:   2
  P: SLIGHTLY BELOW GLIDEPATH
  R: SLIGHTLY BELOW GLIDEPATH

PHRASE #:   3
  P: GOING FURTHER ABOVE GLIDEPATH
  R: GOING FURTHER ABOVE GLIDEPATH

PHRASE #:   4
  P: GOING FURTHER BELOW GLIDEPATH
  R: GOING FURTHER BELOW GLIDEPATH

PHRASE #:   5
 *P: FOUR MILES FROM TOUCHDOWN
 @R: TWO MILES FROM TOUCHDOWN

PHRASE #:   6
  P: TURN LEFT HEADING ZERO ONE FOUR
  R: TURN LEFT HEADING ZERO ONE FOUR

PHRASE #:   7
  P: WIND 1 1 0 A1 1 0
  R: WIND 1 1 0 A1 1 0

PHRASE #:   8
  P: WIND 1 1 0 A1 2 0
  R: WIND 1 1 0 A1 2 0

M = 150    T = 60    VBCLS = 6    VBTV = 30    VCONF = 50

PERCENT CORRECT RECOGNITION:  87.5

WHEN LOW CONFIDENCE ITEMS CAN BE RESOLVED,
PERCENT CORRECT RECOGNITION:  100.0
```

Figure 1. VDC Summary Data — With Prompting

with "slightly below glidepath," so the instructor tells the system to again gather voice reference data for these particular phrases.

Finally, when the instructor is confident in both the basic knowledge of the student and the proper configuration of the speech system*, the student is introduced to the GCA-CTS. In an effort to describe the basic system concept, the student is encouraged to speak any of the GCA phrases he has been practicing. The student listens and finds that the computer is repeating back to him whatever he says! He is amused by a strange "d u u u h h h" when he speaks illegal phrases into the live mike.

The student is anxious to have his performance objectively measured by the computer training system. In order to facilitate his explanation of errors, the instructor commands an automatic freeze whenever the system detects an error. The student catches on very quickly, so the instructor places the GCA-CTS in a fully autcmated mode and leaves the student to himself. Later the instructor returns, reviews the student's performance via hardcopy printouts, and decides to advance the student past several levels into a more difficult syllabus sequence. The student finally completes the entire syllabus and is ready for live GCA exercises.

As new areas for the application of speech recognition are identified and studied, a variety of similar scenarios will also be brought to reality.

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*Ideally, the fully automated system would continually update the speech reference data until some criterion of recognition accuracy was met. At that point, the system would signal the instructor to shift (or automatically shift) to the performance scoring capability.

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PILOT ACCEPTANCE AND PERFORMANCE EVALUATION OF VISUAL SIMULATION

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Boeing Commercial Airplane Company

The primary value of the effort which is the subject of this report is that it represents a novel application of research techniques usually reserved for more academic pursuits to simulation system procurement. The requirement for this test was specified in the document provided to prospective suppliers of the visual simulation system sought by the Flight Crew Training organization of the Boeing Commercial Airplane Company for installation on its moving base simulators for the 707, 727, 737, and 747. The more common approach appears to be limited to reliance on opinions of a few senior flying personnel and members of management. The present study (while not permitting the rigor attainable in the more narrowly circumscribed laboratory experiment) is an example of the extension of research techniques to equipment procurement involving the display of complex perceptual stimuli.

Without a simulation of the extra-cockpit visual scene, simulation of the aircraft is obviously limited to instrument flying (IFR). In the "blind" simulation, the simulator pilot can follow his approach down to a hundred feet or so before he must consider it completed. The value of this type of training cannot be questioned, insofar as safety requires IFR skill when visibility is poor. However, a critical segment is left out of such simulation; a segment requiring precise coordinated responses to the outside scene. The last few feet before touchdown require maneuvers in response to heads-up visual information including the critical flare maneuver. Roll-out, with thrust reversal and braking, obviously entails such visual input. Takeoff is another maneuver in this category as is the somewhat demanding engine-out procedure after rotation.

The savings derived from moving training from the aircraft to the simulator are immediately apparent in that the aircraft is much more expensive. There is, moreover, additional savings in training time because the simulator can be repositioned in $\underline{x}$, $\underline{y}$, and $\underline{z}$ to some desired starting point without taking the time (and fuel) to fly there. Additional savings derive from the opportunity to interrupt the flight at any point to discuss some particular aspect of pilot performance needing attention. Finally, the simulator can be used for training in emergency maneuvers which are inherently dangerous to attempt in the aircraft and under poor visibility.

The summary in Table 1 provides a quick overview of some major advantages and disadvantages of four general categories of visual simulation techniques. The first two are computer-generated; one providing both night and day simulation, while the other is "night only." A third type uses movie film which was obtained on the approach to the airport pictured. The fourth type uses a small scale terrain model (i.e., a solid model scaled down) an optical probe, and a closed-circuit television (CCTV) as its major components.

All four types of visual simulation have inherent weaknesses. The primary limitations of each are listed at the end of the table. The six individual areas of concern are listed in the column on the left.

<u>Realism</u>. The aspect of visual simulation to which most observers are sensitive, initially, is that of realism. Movie film is necessarily most realistic, but, because of optical limitations and film wear, the observer is occasionally reminded that he is looking at cinematography, especially when film scratches form streaks in the field. These provide incidental cues about glide path alignment. The rigid model with CCTV is generally good in its realism, but is limited by the size of the model and by the scale of the model interacting with limitations of the optical probe and the TV display. The computer generated night-only display takes advantage of the fact that points of light are easier to produce in the cathode-ray tube (CRT) display than surfaces would be. The computer generated imagery (CGI) day/night simulation can appear cartoon-like because of the requirement to limit the number of edges. However, if major landmarks and a reasonable amount of other details are programmed into the data base, the dynamic appearance of the scene during an approach imparts a realism which is quite compelling.

<u>Day/Night</u>. The movie film display is limited by the photographic and projection systems;

TABLE 1. VISUAL SIMULATION SYSTEMS COMPARISON
(AS OF JUNE 1974)

	CGI Day/Night	Night Only/CGI	Movie Film	Rigid Model
Realism	Dynamic realism good, static picture cartoon-like.	Good but limited to points of light.	Excellent (except see Resolution).	Good but limited by size of model.
Day/Night	Yes, also dusk.	Night only.	Day only.	Day only.
Weather Variation	Clouds, visibility, runway visual range, and scud.	Clear, obstruction by clouds, visual range and scud.	Fixed	Clear or with veiling glare for haze.
Distortion	Little or none.	Little or none.	Can be severe when off localizer/glide slope.	Some peripherally from optical probe.
Resolution	Good but short of pilot visual capability.	Very good but short of pilot capability.	Generally poor.	Poor (at display)
Depth of Field	Not limited.	Not limited.	Camera limited.	Optical probe and model scale limited.
Primary Limitations	Flicker.	Night only No blue.	Day only Incidental cues, streaking Lag time.	Poor resolution and depth of field. Lag time.

that is, the sensitivity of the film and the amount of light lost in optical systems to provide designed orthographic projection of film originally photographed from a different perspective. Thus, more light is required in the original scene. The rigid model can have incorporated points of light, but a large number of these would generally be impractical and the scale of the model generally makes it difficult for any source to be seen as a point. This precludes the presentation of a night scene with this type of display. The day/night CGI can also present a dusk scene for each of the airports now available in the Boeing data bases.

Weather Variation. The movie film of approaches must of necessity be limited to the weather conditions prevailing at the time of exposure. Some alteration of the appearance of the scene may be possible by "special effects" techniques. The rigid model display, for example, introduces a veiling glare into the scene which is meant to simulate a haze condition. Other than this, nothing was available in these two systems at the time of the review to simulate weather variations. The night-only simulation system was also limited to a clear weather condition at the time of this review. Only the CGI day/night provides for variable altitude cloud tops and bottoms or variable runway visual range (RVR).

Distortion. There is little distortion in either the night/day CGI or the night-only system if the CRT is adjusted properly. The rigid model system may show some distortion in the periphery of the display field because of limitations in the optical probe. The most severe distortion occurs with the movie film and orthographic projection system when the simulator is off glide path. Thus, tall buildings will appear to tilt away from vertical in a distracting way with film displays of this type unless the projection coincides with the original viewing angle.

Resolution. This limitation is one that affects the quality of all the displays, though in differing amounts. None could match the resolution (acuity) of the human eye which, according to clinical refraction standards, is nominally one arc minute subtended at the eye. This visual angle is termed Snellen acuity after the researcher who devised a set of letters with overall dimensions of five units and details (lines, gaps) of one unit. The "average normal" or emmetrope can name the letter when its details subtend one minute of visual angle. The test of visual acuity made with such targets obviously requires some minimum level of literacy and could not be administered to someone who did not know the alphabet. Furthermore, many have finer acuity than the one minute standard, being able to discriminate details of 45 arc seconds or even 30 arc seconds in the Snellen letters. Students of vision are also aware that the visual angle for normals when other types of test targets are used may be smaller or larger than this nominal one arc minute for legibility of letters. For example, vernier acuity (as in reading the minimum perceptible offset on a slide rule or vernier micrometer scale) is about five arc seconds, and minimum visible acuity (single black line against a bright background) is down as low as 0.5 arc seconds. Finally, when it comes to the minimum visible point of light (e.g., a star) it can be almost infinitely small as long as there is sufficient light in it. However, the star source is not infinitely small as projected on the retina because of optical limitations of the eye.

The importance of the foregoing discussion is that the selection of a single value for acceptable resolution in a display such as those being considered here would of necessity be arbitrary in some respect or another. Moreover, the adequacy or meaning of any stimulus depends upon what responses you must make to it in order to reach some desired goal. As a way of stating in general terms our minimum requirements for visual simulation for flight, we ask, "Can the pilot fly to the display?" Stated another way, "Is the visual information sufficient for the pilot to learn what he must for later successful performance in the airplane?" Considering resolution, or any other characteristic of the visual simulation, in isolation will not yield an answer to this question. This is the primary reason for research of the type reported here.

Resolution in the movie film display is generally poor, primarily because of optical considerations. One of the potential virtues of photography, that of using the real scene with all its details, is actually a detriment to its acceptability. Such detail in the visual world provides texture which enhances the appearance of depth. Lack of resolution in its photographic representation thus becomes more noticeable by the impoverishment of this texture. The terrain board (rigid model) also loses fine detail as the image goes through optics and TV display components. The blur is quite noticeable, but is less distracting than that associated with movie film, partly because the terrain model scene is not as complex as the visual world would be in the airplane. The night-only system need only worry about the size of its point lights, and these were good in the displays available to view. The CGI day/night display achieved at best three arc minutes; while this was as good as the night only, it still was too large to match human visual capability.

Depth of Field. The day/night and night-only systems have no depth of field problem, because there are no optical components used to bring the image to the display. Cinematography uses optics but, because of the distances involved, all details outside the cockpit are beyond infinity focus for the camera. The rigid model system, however, does have a problem associated with the foreshortened distances in a small scale model. Point lights (e.g., runway lights) tend to balloon out as they are approached in the simulation, and surface details become blurred. One partial solution to this problem is to change over to a terrain model of larger scale (representing a smaller ground area) with correspondingly larger details. Such an approach obviously complicates the system and introduces undesirable discontinuities.

Primary Limitations. Each of the four general types of visual simulation systems has unique advantages and unique disadvantages, a few of which have been covered in the preceding discussion. This brief treatment will touch on the limitations which appear most specifically related to each simulation technique. The CGI day/night system has, in the day scenes, a tendency to flicker as the detail begins to correspond to one raster line. For example, if runway markings are displayed from several miles distance, they appear to shimmer and flicker. Fortunately, this kind of problem can be overcome by waiting until the aircraft is closer to the runway before introducing such details into the scene. Some flicker remains nevertheless, and the removal of this negative feature of CGI day scenes awaits future improvements in the technique.

The night-only scene has, in addition to the restriction to night scenes, no blue light in the scene. In cases where this color may be desired, for example in runway edge lighting, it is simply unavailable in the present night-only simulation.

The movie film disadvantages lie primarily in the incidental cues to performance error. Distortions arising from the anamorphic projection system could provide a clue to glide path deviation which the student pilot might learn to use instead of the appropriate cues. A more disturbing artifact observable in cinematographic systems of visual flight simulation is the streaking which appears in the display from scratches on the film after repeated use. Flying to the streaks instead of to the projected scene would be somewhat difficult for the student to avoid, especially when he is anxious to "look good" to the one who is evaluating his progress.

The major limitations to the use of terrain models with a "flying optical probe" and a CCTV have already been discussed above. They are poor resolution in the display and restricted depth of field, the latter causing nearby details to be blurred. A further consideration which causes hesitation on the part of prospective buyers of visual flight simulators is that a not insignificant volume of space is required for the terrain models themselves.

Evaluation Criteria. The foregoing discussion has been concerned primarily with the purposes for which visual simulators are purchased and the good and bad points of the various general techniques of visual simulation. It was suggested in the introduction that the important contribution of the effort herein reported is the use of the research techniques of the experimental psychologist as a method of ensuring compliance by the supplier with specifications the user would like to impose on system performance.

Uppermost in the researcher's mind, of course, is the quantitative data through which he asserts his faith in the scientific method. In exploratory studies like this one, many measures must be examined in the search for the best indices of pilot performance.

In addition to the adequacy of the design of the simulator as an aid in the training of flight crews from the standpoint of essential elements for meeting specific behavioral objectives, its acceptability in subjective (perhaps we should say "esthetic") terms is important. If it "looks funny" to the student, the visual simulation may be ineffectual for its major purpose. Therefore, it was desirable to get the instructor pilots who flew the simulator in our evaluation to offer their opinions about the acceptability of the visual simulation. We were also interested in the reactions of these instructor pilots to the potential for improved flight crew training provided by the addition of the visual simulation to our moving-base simulators.

The ultimate proof of the value of any training aid such as a simulator is the degree to which the learning later on transfers to the operational task. Although this type of evaluation is part of the Boeing Flight Crew Training visual simulation test program, it was not included in the procurement specifications because the magnitude of such a test would impose a delay in acceptance which would have been unfair to the supplier.

Visual Simulator Evaluation

Test Facility. All quantitative data was obtained from simulator readouts as the pilots made their approaches and landings in the Boeing 737 and 727 Flight Crew

Training simulator at Boeing Field.

Pilots. The data was provided by 16 Boeing instructor pilots currently active in that assignment.

Data Base. The scene consisted of the airport and environs at Moses Lake, Washington (Grant County Airport). The runway is 13,500 ft. by 400 ft.

Flights. Each pilot made eight approach/landings.

Experimental Conditions. Three variables were treated in the test. The first was the use of instrumentation. While all flights were made without altimeter visible, on half the flights (4) the pilot was not given glide slope/localizer information either. The flights were evenly divided between day and night approaches (4 each). The third variable concerned visibility. Under the good visibility condition, the runway visual range was 200,000 ft. and visibility was 30 nautical miles, while the limited condition consisted of a runway visual range of 36,000 ft. and visibility of 20 nautical miles. As with the other two variables, the two visibility conditions were evenly divided, 4 and 4. All three variables are combined in counterbalanced fashioned to ensure that interaction pairings are evenly distributed. The actual presentation order was mixed up (semi-randomized) to keep order effects to a minimum. (Fig. 1)

Approach Path. The simulator was positioned at 1330 ft. above the runway level and 4.7 nautical miles out, on glide slope (2.5°) at the outer marker. There was a wind coming from the right at 20 knots. This wind dropped to 10 knots as the aircraft passed over the middle marker (0.5 n.mi.) and dropped further to zero at 50 ft. above the runway. The touchdown point was 0.3 n.mi. down the runway beyond the threshold.

Performance Measures. At intervals of one second, seven items of information were printed out. They were 1) time from start of descent, 2) ground distance, 3) groundspeed, 4) altitude, 5) distance left or right from localizer, 6) rate of descent, and 7) touchdown point (wheels are touching). These measures were chosen as the ones most likely to include valid indices of performance. When sufficient data are amassed they hopefully will permit us to select a couple of predictors which will account for most of the variation in performance among pilots.

Procedure. Prior to entering the simulator cab, the pilot was given an instruction as to the nature of the task and the purpose of the test. In addition to the strictly informational content of the instruction, an emphasis was placed on the evaluation of a visual display as opposed to an evaluation of their flying skills. However, they appeared to react to their participation such that they could be expected to do their best.

Training. To ensure at least a minimum level of familiarity with the characteristics of the simulator and the visual display, four practice trials were run before the eight test trials were initiated. In the first of these practice trials, the simulator was "flown" with all instruments available but without a visual display. The starting altitude was 1330 ft. and the distance from the glide slope touchdown point was 30,400 ft. The runway was 400 ft. wide and 13,500 ft. long and the glide slope intersection with the runway was 1840 ft. beyond threshold.

The second practice approach was the same as the first except that the daylight, high visibility scene was present in front and side windows. The pilot was reminded to make his touchdown at the same point (glide slope 1 runway intercept) instead of a point closer to runway threshold following the usual practice with good VFR conditions.

The third practice approach differed from the second only in that it used a night scene. The fourth and final practice approach was identical to the first, with no visual simulation but with all instruments available.

Data were taken on the practice runs, but they were not used for the main test analysis. The analysis of the practice data was undertaken separately for the purpose of determining the effect upon performance of first exposure to the visual scene (see Appendix B).

Presentation Order. To minimize the possibility that variation in performance across conditions could be interpreted in terms of the order in which they were presented, partial randomization was used for the eight test runs. For each combination of time of day and visibility condition, both instrument conditions (with and without glide slope) were run before proceeding to the next such combination. This was deemed adequate to obviate concerns about order effects in the data and it had the advantages of reducing the opportunity for errors in setting up conditions and reducing the time needed for the completion of a session.

Questionnaire. After all test runs were completed, each pilot was queried about certain aspects of the simulation (see Appendix A). The questions referred to such things as realism in the visual simulation, potential improvements in training arising from the addition of visual simulation, its limitations and the quality of its interaction with motion simulation. After a final

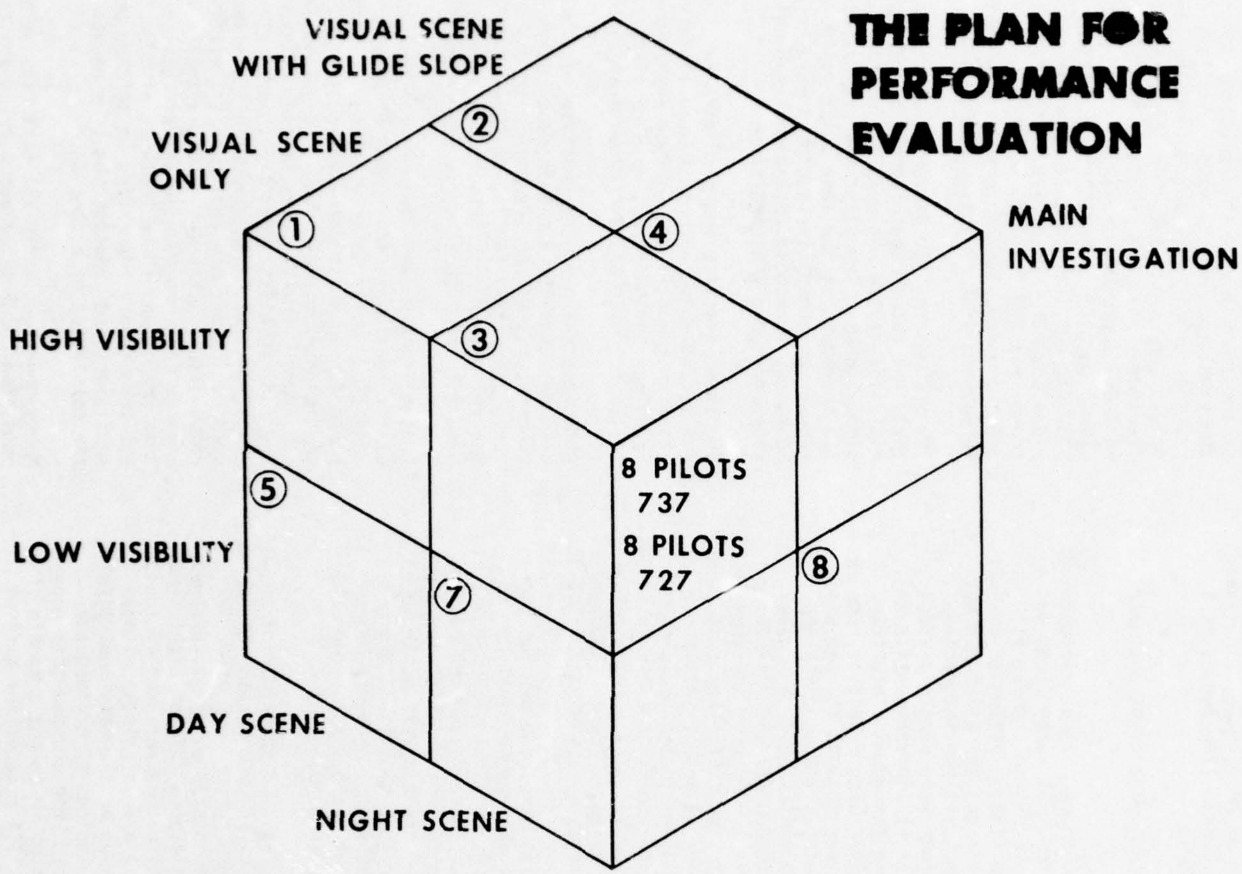

Figure 1. The Plan for Performance Evaluation

question about his flying experience, the pilot was encouraged to comment freely about any aspect of the simulation or test he wished. The comments made in response to the questionnaire and those made freely before or after it, were recorded on tape for later transcription.

Results. Figure 2 shows the average altitude along the approach path. The path flown by the pilots when they had no glide slope information tended to average slightly lower than when this information was available. The raw data show this deviation from glide slope (glide slope is the straight line designated "theoretical" in the figure) to be due primarily to performance in the approach to the night scene with good visibility but without an altimeter. This observation is in agreement with a similar one made in prior research by the present authors. It was noted that pilots who were skilled enough to be flight crew instructors tended to fly low when moving over dark terrain on a night visual approach when they lacked altitude information. Upon making this observation in the prior study, we hypothesized that the pilots were choosing a path which appeared to them to be straight, but which in fact was curved because it was based on the maintenance of a constant visual angle subtended at the eye by the group of lights in the scene. This path is indicated by the dashed line in Figure 2. Inside of two miles the path flown by the pilots in this study appears to be a compromise between the theoretically perfect straight line glide slope and the equal visual angle path.

Statistical analyses were performed on the digital data which was read out at one second intervals. In the analysis of variance, the results showed three statistically significant ($p < .05$) effects. These are the starred means in Table 2. Two of the effects do not appear to have much practical significance: A slightly higher average airspeed when visibility was lower and an average of one second longer before touching down when the glide slope information is added to the visual scene. The increase in airspeed with lower visibility was only 1.4% and the increased time with glide slope information was only 0.7%, hardly an observation worthy of much attention with our present level of sophistication in making such measures.

The third effect relates to the distance from where the glide slope intersects with the runway to the touchdown point. This distance (the X dimension) is recorded in feet, positive in sign until the glide slope/runway intercept is passed where it becomes negative. When the glide slope information was present, landings tended to be "long" with TD point a little beyond point zero. Touchdown without glide slope information available was short of point zero by over 200 ft. on the average.

It might be interpreted that the use of glide slope leads to better approach and landing performance on the basis of the difference observed between the two conditions. However, it may be that these pilots were merely landing in a manner which is good practice in the airplane regardless of the instruction to touchdown at the glide slope/runway intercept point. Certainly, it is good practice in general to set the airplane down as soon as possible (with some reasonable margin) in order to have the maximum available distance for rollout. However, there are at least two other hypotheses which could also account for this result. The display was rather bare of ground lights between one and two miles from runway threshold, and this may have made altitude judgment more difficult to do visually. Also, the points of light were never as small as the theoretical limit of 1.25 arc minutes of visual resolution for a point of light; all were larger than 3 arc minutes. There is no way to determine the correct exaplanation in the absence of the necessary data. Finally, with an airspeed of 216 ft. per second the observed difference cannot be said to be anything but small regardless of its statistical significance. These tests were based on the data recorded in the interval just before touchdown and the criterion measure was the distance between touchdown point and the intersection of the glide slope with the runway.

Rather than use the obvious measure of rms deviation from glide slope and lateral distance from runway centerline as the measure of performance along the entire approach path, the data recorded just before passing over the middle marker was used in the second analysis of performance. In addition to the problem of time and cost, there was the question of selecting the appropriate sensitive criterion measure. The data showed an initial drift off localizer at the start of the descent which appeared to be in excess of what the pilot could compensate for. When questioned about it, pilots indicated that they deliberately tested the strength of the side wind by letting it blow them off course for a period of time before trying to correct for it. This appeared to be an efficient way to establish the crab angle necessary to maintain the aircraft on localizer for the remainder of the descent path. Therefore, because of the individualistic approach adopted by the pilots (some allowed a little drift, others a lot), rms flight path deviation seemed inappropriate as the measure of quality of performance. There are many deviations from a straight-in approach on glide slope and localizer which

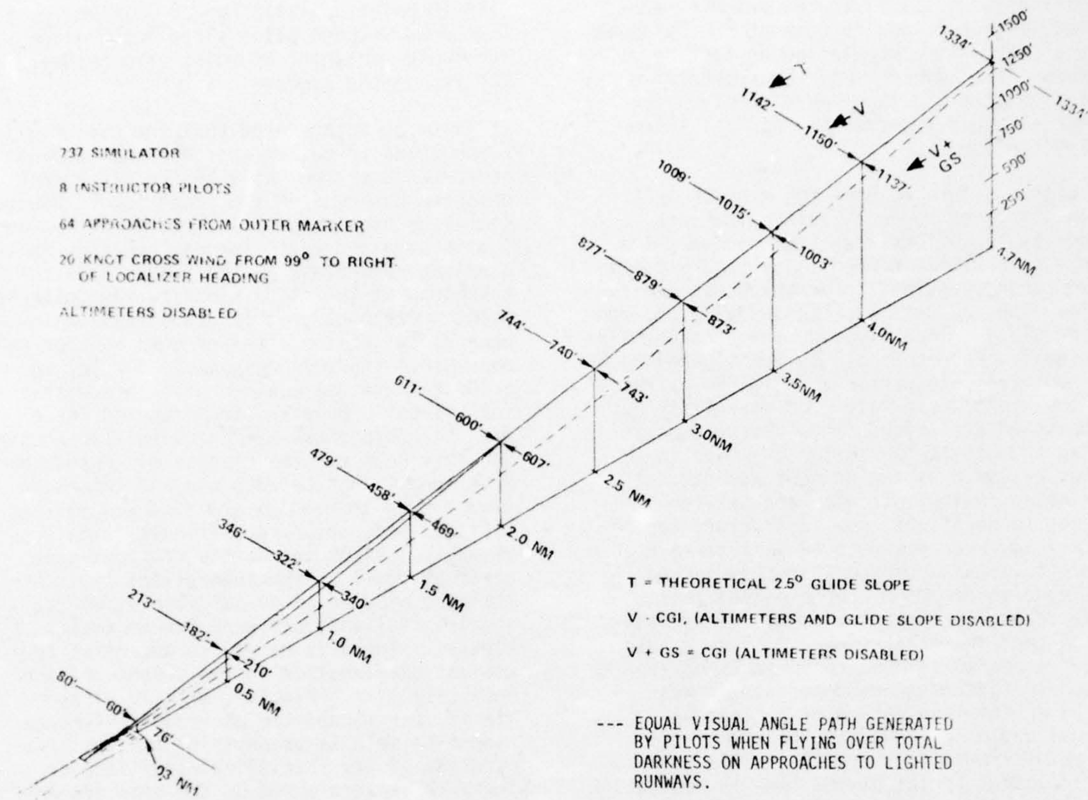

Figure 2. Approach Altitude as a Function of Distance Computer Generated Image Evaluation

TABLE 2. 737 CGI EVALUATION ANOVA CELL MEANS TOUCHDOWN

	TIME OF DAY		VISIBILITY		DISPLAY	
	DAY	NIGHT	GOOD	LOW	VISION ONLY	GL SLOPE + VISION
x	83.5	105.1	91.3	97.4	243.0*	-54.4
y	7.7	11.9	14.1	5.4	7.3	12.2
z	-5.88	-4.42	-4.76	-5.54	-4.59	-5.72
Airspeed	218.	215	215	218*	216	216
Time	137	138	138	137	137	138*

* P .05

would not cause the pilot making them to be downgraded in his performance evaluation; a criterion measure which did not take this into account might well be considered unrealistic.

Meeting a designated glide slope touchdown point is also somewhat arbitrary in that the ILS is meant to be used only to bring the aircraft in sight of the runway, not to permit "blind" landings. Flaring the aircraft too soon or too late is a recognized error, although there is certainly a range of acceptable flare points. Future research in the evaluation of the quality of simulation for flight crew training must emphasize the importance of the appropriate criterion measures.

For the purposes of the test reported here, a rough measure was adequate in that the major concern was to demonstrate the adequacy of the CGI visual simulation. For tests demanding greater sensitivity (i.e., designed to show the existence of smaller differences in pilot performance) some other, perhaps less obvious measures should be developed. We chose the glide slope deviation at the middle marker as being sensitive to the quality of pilot performance without appearing too arbitrary a measure. The rationale was that at a point just prior to passing the middle marker, where the crosswind dropped from 20 knots to 10 knots, the pilot had had sufficient time *under* constant conditions to get on localizer and at the proper altitude to make good touchdown about 15 seconds later.

The data were taken from a point just beyond 0.6 n.mi. from runway threshold. These data (Table 3) showed that the mean altitude for the approaches made without glide slope information was 25 ft. lower than the corresponding altitude for approaches made with glide slope deviation displayed. This was calculated as statistically significant, with a probability of less than 5% of being attributable to chance variation.

The effect of visibility on altitude appears to be limited to night approaches ($p < .05$) with good visibility leading to lower altitudes on the average. The common sense explanation for this would appear to be that a higher approach provides a margin of safety for the lowered visibility situation. This, of course, is mere speculation since the test was not designed for such a hypothesis.

Although the difference in airspeed of 2.5 knots between "good" and "intermediate" visibility levels is statistically significant ($p < .01$), guessing at the probable cause for the difference is difficult unless one resorts to some supposedly correlated observation, such as the relationship between altitude and descent rate to air speed. Thus, in line with such an argument, air speed would be greater at the higher altitudes and higher rates of descent (although the latter was not significant at $p < .05$ but only between this level and $p < .10$). This manner of reasoning, while speculative, is indicative of the necessity to treat performance realistically in terms of its inherent complexity rather than to select in arbitrary fashion something which appears to be easy to measure. Any instructor pilot knows that he must evaluate the quality of student pilot performance in terms of a four-dimensional envelope involving where he is at a given point in time (three dimensions) and how he got there (4th dimension or time). There is not only some latitude which represents acceptable performance but the dynamic aspect must also be considered in its assessment.

An example could be given from the present evaluation. Pilots were told that the primary criterion measure would be the distance from runway centerline/glide slope intercept to the point where they actually touched down. One pilot set down somewhat harder than good practice would dictate, presumably in conformity with what had been requested of him, when touching down a little farther down the runway would have been much better in the airplane itself. He was then told that hitting the target TD point was not to be accomplished in *violation of other* considerations concerning good flying practice.

The last item listed in Table 3 on performance at 0.6 n.mi. out is azimuth or distance from centerline alignment. Although the means for both good and intermediate visibility conditions are close to centerline, there is a statistically significant difference ($p < .05$) between the two with the "intermediate" slightly further left of centerline than the "good" condition. The most likely assumption as to the cause of this difference would appear to be that maintaining the proper crab angle with a 20 knot crosswind is more difficult with reduced visibility.

Conclusions. This test has demonstrated conclusively that the computer generated image display provides a visual simulation which is acceptable to crew training personnel (eight instructor pilots in the 737 and another eight in the 727 simulator) in terms of its probable utility for improved efficiency in training. It can be "flown" to touchdown without altitude or glide slope information using only the visual feedback from the displayed imagery. The test yielded data which were stable enough to show small differences as being

TABLE 3. CGI EVALUATION

PILOT PERFORMANCE WITH 737 SIMULATOR

ANALYSIS AT 0.6 NM FROM GLIDE SLOPE ORIGIN

JUST BEFORE MIDDLE MARKER AND WIND SHEAR (20 TO 10K)

DISPLAY

ALTITUDE	VISION ONLY	VISION + G.S.	
	210.9 FT	235.4 FT	P < .05*

TIME OF DAY X VISIBILITY

ALTITUDE	VISIBILITY GOOD	VISIBILITY INTERMEDIATE	
DAY	224.5 FT	225.2 FT	P < .05*
NIGHT	209.8 FT	233.1 FT	

VISIBILITY

	GOOD	INTERMEDIATE	
SPEED	127.9 K	130.4 K	P < .01**
TIME	1.88 MIN	1.866 MIN	P < .10
DESCENT RATE	9.05	10.29	P < .10
AZIMUTH	55.1 FT LEFT	68.8 FT LEFT	P < .05*

statistically significant.

All of the instructor pilots participating in the test felt that instruction would take less time and require less time in the aircraft itself. An example of the benefits they felt would be derived from the use of a day/night visual simulation is the transitioning from one aircraft type to another. The visual scene through the front window on the approach is an important cue for maintaining proper aircraft attitude on the approach. This is especially important in transitioning from propeller-driven airplanes to jets, where the pitch attitude is nose-high on the approach.

The most valuable outcome of the test (beyond acceptance of the visual simulator) regarding future potential for the simulator is related to its apparent effectiveness for the discrimination of fine differences in pilot performance. All of the landings made in the simulator during the test were good landings as one would expect with instructor pilots.

In Table 2, for example, where "visual plus glide slope" is compared with "visual" alone, a difference in speed of only 2.5 knots is determined to be statistically significant ($p < .05$). Although, as mentioned previously, the practical significance is not immediately apparent, the implied stability of this measure is encouraging in its unexpected sensitivity. Instead of relying solely on gross "go, no go" subjective evaluations of pilot performance, flight crew training personnel may be able to use more subtle indicators which are also more objective. The discovery of such indicators requires serious research efforts, but the availability of good simulator facilities with appropriate recording equipment would be required. It would not be feasible economically to attempt to develop such measures in the aircraft.

In addition to their potential value for finer measures of pilot performance, the development of such indicators may be of direct benefit in the training process itself. Complex behaviors such as those involved in the piloting of aircraft must in part be learned by a "shaping" process. Instead of instructing the student as to the precise manner in which an activity is to be carried out, the instructor tells the student the desired results and rewards him when he is able to achieve it. The student learns "how it feels" when performing correctly without being able to verbalize it entirely. Because this shaping process is made up of many individual components anything which would permit the latter to be learned separately may enhance training. An example would be the landing "flare," the transition from the approach to the touchdown and roll-out. This maneuver cannot be verbalized in such a fashion that the student can slavishly follow a set of instructions. He must carry out a coordinated, smooth maneuver based on the "feel" of the aircraft. Flight crew training personnel can benefit from recordings of performance not only in having a permanent record to show the student but also to study for the purpose of finding additional cues to performance variation, cues which may point to a problem early on, before bad habits are built up.

Recommendations. Now that the visual systems have been installed on all four Boeing Flight Crew Training simulators (707, 727, 737, 747) and have been demonstrated to be effective for simulated flight, maximizing their utility requires answers to questions for which there are no ready answers. For example, how complete can simulator training be made? Is it conceivable, given the requisite FAA approval, that the pilot could be certified in the simulator? If not, how close to this can we get? Would the training function be further enhanced by increased computer capacity for the visual system? Just how well does training in the simulator transfer to the aircraft?

The Boeing Company Flight Crew Training organization is developing plans for a research program to provide the necessary data. These involve the determination of sensitive measures of pilot performance which will provide quantitative criteria for the evaluation of training. The research program, expected to extend over a period of several years, will use the present visual system to establish baseline performance. From this baseline both greater and lesser degrees of completeness of simulation will be evaluated.

In summary, the task of this research effort is to:

1. Develop valid and reliable quantitative measures of pilot performance involving reliance on vision.

2. Establish "baseline" performance with the present visual system.

3. Determine the level of display fidelity (e.g., resolution) below the present system level which would result in significant degradation of pilot performance.

4. Determine the level of display fidelity which would result in significant improvement in pilot performance.

5. On the basis of this research effort,

develop and document a set of guidelines to assist our commercial customers and other interested parties in the selection of visual simulation systems that will meet mission goals and at the same time be cost-effective.

The first task, that of developing valid and reliable measures of pilot performance, is both critical and difficult. The obvious place to begin is with questions submitted to senior instructor pilots regarding their current criteria for assessing pilot performance, both in the airplane and in the simulator. The data thus obtained can be analyzed to develop correlative physical measures available from instrumentation on the aircraft and on the simulator. A significant portion of this development effort must be spent with senior pilots generating test data to establish validity and reliability. The resulting measures can then be used in a series of studies relating simulator training to pilot performance in the aircraft.

APPENDIX A

INFORMAL QUESTIONNAIRE

Instructions: Would you please provide us with your comments about the visual simulation now that you have completed the twelve approaches to Grant. Co. Airport. You may write your comments in the space provided below each question. Or if you prefer you may use the tape recorder and identify the tape to us by the experimental code number. CGI-1.

(1) How realistic did the visual simulation appear? Did your impression of it change with time on the task?

(2) Was there anything annoying about it?

(3) Did there appear to be any discrepancy between visual feedback and motion feedback?

(4) What portions of current training or recertification done in motion base simulators do you think might be improved by the addition of visual siumlation?

(5) What portions of training or recertification now requiring actual flight time do you think might be done adequately with a simulator having this visual display?

(6) Was there anything missing in the visual display that you think should be there?

(7) Do you have experience flying into Moses Lake? Day? Night?

(8) How recently had you flown the 737 simulator before the approaches you have just completed?

(9) Would this kind of simulation have any particular value in the training of pilots who fit the category of "minimum time pilots?" In what way?

(10) Would you speculate for us on the possibility of a visual simulation like this permitting the actual certification of airline pilots without any checkout time in the airplane itself?

(11) Do you think that the visual display is critically evaluated by this test?

(12) Have you had experience with any other visual simulators? Please compare.

(13) Were the side windows helpful in these straight in approaches? How?

(14) To help us make a composite profile of all 16 pilots that will participate in this evaluation would you provide the following information on your flying and instructor experience?

Overall number of flying hours you have logged ____________

Number of hours logged in jet aircraft

____

Number of hours in 737 aircraft

____

Air Transport aircraft you are qualified in

____

747 ______ 737 ______ 727 ______

707 ______ DC-10 ______ DC-8 ______

DC-9 ______ Falcon ______ Lear ______

Others ______.

APPENDIX B

TRAINING TRIALS AS A PRELIMINARY EXPERIMENT

Introduction. The research and operational people were concerned about the completeness of the visual scene as an information source. It was hypothesized that if the visual scene contained sufficient information, very experienced pilots could land on such a scene the very first time they made an approach to the image.

The method. Four practice trails were given each of the 16 pilots before they made their

eight approaches of the main experiemnt. The four training trials were ordered as A_1, B_1, B_2 and A_2. The A conditions were runs without the visual scene but with all instruments available to the pilot. The B conditions also provided all instruments and the visual scene, B being a day scene and B_2 a night scene. The results of the two A conditions were combined so that the practice effect was an average of the first and fourth trials. The two B conditions were averaged and represented the second and third trials. Such a counterbalancing should minimize the practice effects due to presentation order. All procedures were the same as in the main experiment as discussed earlier, with the one significant difference that in the training trials barometric and radio altimetry were available under all conditions.

The "instrument only" trials were designed to give, in addition to the pilots very recent practice trials, a basis for experimental comparison. Normally, pilots never fly to touchdown on instruments without seeing the runway, so this experimental condition has no operational counterpart. It provides only a measure of the pilot's instrument flight skill at that moment of practice, and a statistical comparison with the instrument + visual scene performance trials.

The same dependent measures were used in this preliminary experiment that were used in the main experiment. Two major comparisons were made: (1) The area (footprint) at touchdown and (2) The descent rate at touchdown. The "footprint area" was defined as $\pm$ one standard deviation in x and y from the mean touchdown point and these values converted into an area.

The Results. The visual scene reduced the "footprint area" from 453,024 square feet to 32,528 square feet, a reduction of 13.9 times due to the presence of the visual scene. The rate of descent at touchdown was reduced from 11.07 ($\pm\sigma$ = 15.74 to 6.4) feet per second to 5.04 ($\pm\sigma$ = 8.11 to 1.97) feet per second. This magnitude of change of 6.03 feet per second could have occurred by chance only once in a thousand replications of this experiment. The comparison information is that the design limit for the aircraft gear (737) is 10 feet per second for maximum gross weight of this aircraft.

Summary. Although a very limited experiment in number of pilots, trials, and replications, these data are intriguing. To maintain one's perspective, the reader should recall the 20 knot cross wind which sheared twice close to the ground (200' and 50' in altitude) and made these approaches difficult even for experienced instructor pilots.

Under these difficult conditions and on first exposure to the visual scene the eight 737 pilots were only 86' short and 29' to the right of the glide slope intersection on touchdown. This would be an excellent performance without the windshear. The rate of descent at touchdown compares very favorably with the NASA data on touchdown rate in their Ames simulation studies with many more trials. The assumed average touchdown rate of "good landings" is about 3 feet per second in air transport operations. This is only 2 feet per second better than these pilots did on their first and second approach to the computer generated image. These data imply that the information content of this combination of night and day scene was adequate for experienced pilots to make successful first trial landings. This CGI scene was a replication of a very familiar runway and airport for all these instructor pilots.

APPENDIX C

CGI PERFORMANCE EVALUATION INSTRUCTIONS TO PILOTS

Purpose of Test. We are evaluating a new visual simulation system built by General Electric according to Boeing specifications. The visual scene is generated by a computer program and displayed in color on a cathode ray tube. This scene contains major landmarks useful in navigation. Perspective changes associated with changes in aircraft attitude and position provide the visual feedback to the pilot related to his flight path.

Our purpose in conducting this exercise is to evaluate this display in as systematic a fashion as conditions will permit. It is not an evaluation of the pilot's flying ability since this ability is a necessary assumption in our analysis of capabilities of the display.

Procedure. After an initial practice period to ensure familiarity with the task and with the appearance of the scene, you will be asked to make 8 approaches to a visual simulation of Grant County Airport, at Moses Lake. You may recognize familiar landmarks.

Visibility, time of day, and availability of instruments are the major variables in the test. In each case you will start at 4.7 nautical miles out at an altitude of 2500 ft. (MSL). There is a 20 knot wind from 45 degrees right of runway heading at starting altitude. On your approaches we are

asking that you fly the simulator on the basis of the information directly available to you. The man in the right seat will not make the standard callouts; he will limit his assistance to configuration changes as you direct.

We are asking that you select the same touchdown point in all conditions, that correspond to an IFR landing. Also, we ask that you attempt to keep lined up with the runway centerline when the visual scene is present. The criterion variable will be deviation from prescribed flight path.

Mental Set. Each participant should view the test of this visual simulation as though he were a researcher. This means: 1. Objectivity (not prejudiced for or against the display), 2. Belief in the goals of the study, 3. Appreciation of the value of quantitative analyses, and 4. Confidence in the validity of the generalizations to be made from the data.

To re-emphasize something mentioned earlier, this is not a test of your flying ability and the data you provide will not be reported in any way that reflects your performance on this task as an individual. We respect the fact that your professionalism will yield the best data obtainable; that's why you were chosen to participate.

Your assistance in this research effort is sincerely appreciated and it is hoped that the experience is both interesting and enjoyable.

APPENDIX D

INFORMAL COMMENTS BY EIGHT PILOTS FLYING THE BOEING VISUAL SIMULATOR

Relevant Experience

- From 8 to 15 thousand hours of flying (Ave 10,700 hrs).
- From 2 to 7 thousand jet hours (Ave. 4,700 hours).
- From 150 to 2,300 hours in 737 (Ave. 960 hours).

All had made a number of approaches to Grant County Airport, the scene used in the test.

Realism of visual simulation?

- All pilots thought the display was realistic and good enough to fly to without instruments.

What is missing?

- One pilot said that greater definition would be "nice."
- One pilot said that the red light was missing from the glide slope shack.
- Six pilots had nothing to mention.

Synchronism between motion simulation and visual simulation?

- Three pilots mentioned experience with other visual simulations. These included Vital II, Link Vamp, Redifon, and Novoview. All three preferred the Boeing visual simulation built by General Electric.

Distractions and "petty annoyances"

- The few negative comments volunteered by pilots who served in the test relate to appearance of scintillation in parts of picture at various times or a tendency for "threshold size" objects to pop into view. In a couple of instances pilots noticed some streaking. One said it reminded him of "tracer bullets."

ABOUT THE AUTHORS

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AUTOMATED SCORING OF INSTRUMENT FLIGHT CHECKS

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U. S. Coast Guard helicopter pilots receive annual instrument and emergency training in the Variable Cockpit Training System simulator. Many portions of initial aircraft transition training are also conducted in the simulator. Initial instrument ratings as well as annual instrument renewals are given on the basis of simulator checkrides, which are automatically scored by the computer. Scores are kept for as many as 12 parameters at a time. This paper discusses the first three years of experience with automated scoring. Moderate correlations were found between subjective instructor scores and automated scores. Although not useful for individual pass-fail decisions, normative comparisons of the automated scores are responsive to changes in the training program.

BACKGROUND

Coast Guard helicopter pilot training has been conducted at the Aviation Training Center in Mobile, Alabama, since 1967. A study was conducted in 1969 to determine future Coast Guard aviator training requirements (Hall *et al*, 1969). After a thorough investigation of operational pilot tasks, several training goals were identified which had general applicability and might best be taught in a central location. Each training goal was evaluated with respect to simulation technology available. Decisions were then made concerning which simulator capabilities might be implemented to enhance training of helicopter pilots (Caro *et al*, 1969). For example, very little saving of flight time was envisioned through use of a visual system because of its limited ability to simulate the water environment. On the other hand, many helicopter malfunctions would require all six degrees of freedom in motion simulation.

Based on these two papers, the entire training program was revised. Concurrently, a flight simulator was designed and built. Both efforts came together in 1973 as the Variable Cockpit Training System (VCTS) became operational. The VCTS utilizes a highly sophisticated, computer-based flight simulator built by Reflectone, Inc., which consists of two separate cockpits. Each cockpit duplicates one of the two different types of Coast Guard helicopters.

SYSTEMS APPROACH TO TRAINING

Implementation of the VCTS was a major shift away from the traditional concept of aviator training towards a program based on the systems approach to training. The major concept underlying this new training system has been in the area of aircraft systems knowledge. The present methods stress teaching the student how to operate the system as opposed to giving him detailed explanations about how the system operates.

INSTRUCTOR AS TRAINING MANAGER

The key to success in using this new approach has been the instructor's background and the role he plays. Instructors are carefully selected from a group of operational pilots who have expressed a desire to come to the training center. In addition to extensive operational experience, each instructor pilot receives instruction in managing the training progress of his students. While working with a group of students, the instructor becomes involved in all facets of the course of instruction from briefing, through the simulator, to the aircraft.

PEER TRAINING

One instructor and two students work together as a team. Each student spends half the time in the copilot seat and the other half in the pilot seat during simulator training periods. Simulator flights then become primarily practice and validation sessions where students must react as a team to situations covered in the briefing and reading assignments.

For those courses involving actual flights, an additional instructor pilot is also provided. He flies in another aircraft with the second student. This team stays together until the pilots have reached course standards in the basic helicopter maneuvers, instrument and emergency procedures and systems knowledge. The students then fly with other instructors for training in operational maneuvers and for aircraft and simulator check flights.

Briefing and debriefing sessions are conducted in a dialectic manner. Questions are used to lead students from one concept

to another. In many cases one student may be able to shed some light on a point of confusion. Since the program makes use of the proficiency based learning concept, the length of any given course will vary considerably depending on the student's past experiences and his ability to progress through the new material.

The methods now in use have resulted in overwhelming acceptance by the students. They invariably praise the concept of personalized self-paced learning.

TRAINING COURSES

Although the facilities and methods described have been used for a variety of purposes, the major emphasis is on recurrent training. Transition training and initial qualification training are also conducted on a regularly scheduled basis. Students in all courses are qualified pilots.

Pilots who are current in one or both of the helicopter types come to Mobile annually for recurrent training. This involves one week of intensive training in instrument and emergency procedures conducted completely in the simulator. Upon completion, the pilot's instrument rating is renewed for another year. Approximately 500 pilots a year go through this course in one cockpit or the other.

Transition training is offered in each specific type of helicopter. Pilots who have never flown the helicopter to which they are being assigned take from three to six weeks to fully qualify, depending largely on their rate of learning and previous experience. Approximately 30 pilots go through this course in each helicopter annually.

In the third major course, fixed-wing pilots are given their initial helicopter qualification in the HH-52A single engine helicopter. Approximately 18 pilots per year go through this course. The end-of-course objectives for the Qualification Course are the same as for the HH-52A Transition Course. For planning purposes, an additional week is allowed to acquire the basic helicopter skills.

The switch in training philosophies and the implementation of the VCTS have resulted in a much higher quality of training at a reduced cost. Emergency procedures are practiced in the simulator that are not possible in the aircraft. The simulator operating costs are relatively stable at $65 per hour while aircraft operating costs are high and rising rapidly. Cost figures for Coast Guard helicopters are roughly ten times as much for the HH-52A and 15 times as much for the HH-3F.

OBJECTIVE SCORING TECHNIQUE

Recent interest in objective scoring of pilot performance has grown out of some longstanding uncertainties. In the one-on-one evaluation situation imposed by most training aircraft it is impossible to achieve totally objective performance scores. Training supervisors have had to make judgments concerning quality of training and student progress based on scores collected by a number of instructor pilots.

Many efforts have been made through the years to increase the objectivity of scoring by check pilots (Smith *et al*, 1952; Povenmire *et al*, 1973; Koonce, 1974). In every case it was found that reliability between observers increased when scores were based on instrument readings rather than outside references or quality judgments. With present computer technology,it is quite simple to automatically score instrument readings much more accurately than can be done even with an expert human observer.

The Coast Guard has been collecting data on a computer scored operational instrument checkride for over two years. We will herein report some preliminary results and point out some pitfalls to others presently designing similar systems.

Automated Checkride

The automated checkride incorporated in the VCTS simulator records frequency and time out of tolerance for 12 flight parameters. A simple computer language called SANSKRIT is supplied by Reflectone, Inc., to allow Training Division personnel to design checkrides.

Each maneuver is broken down into segments for scoring purposes. Errors are accumulated and stored for as many as nine segments of a maneuver. Each segment may be further divided into as many as 15 blocks to ensure proper sequencing through the segment. The checkride is automatically sequenced when the student reaches the "END CRITERIA" of each block.

Maneuvers are ordered in such a way as to simulate an operational instrument mission. The instructor acts as an FAA controller giving clearances and weather information which would be heard on an actual flight. He also

records information which will not show up on the recorded checkride such as cockpit procedures, planning and crew coordination. Prior to the checkflight, the student plans the flight as he would in the real world including all required paperwork.

A typical checkride commences with an instrument takeoff from Bates Field in Mobile destined for Gulfport 30 miles away. The student in the pilot seat is automatically graded on his takeoff, his airways tracking as he flies to Gulfport, and his holding procedures simulating delays for traffic or weather. He will make several approaches down to Minimum Descent Altitude. He is assisted by his flying partner acting as copilot. Malfunctions are automatically inserted along the way to allow the instructor to subjectively grade both crewmembers in their teamwork, judgment and troubleshooting strategy. From an experimental standpoint, the copilot provides an unwanted source of variance. However, greater realism and training value are achieved by having two students act as a crew.

Establishing Criteria

Special attention must be paid to designing "end criteria" for each checkride block in order to assure proper sequencing. End criteria must be met not only by any acceptable procedures, but by any conceivable procedure. If poor performances do not produce a completed record, the lower end of the distribution will be eliminated.

"Scoring criteria" must be developed to allow any of the acceptable alternatives to be scored equally. Many operational instrument maneuvers, such as procedure turns, allow alternative procedures which are equally correct. This limits the number of items that can be scored during a given block.

The computer automatically prints out a record of error scores for each maneuver at the end of the checkride provided that all end criteria have been met. These records are retained in permanent storage for complex data analysis and reporting.

ANALYSIS AND DEVELOPMENT

Several questions must be answered before this data can be used. First, how many records must be collected before the data reaches an acceptable level of reliability? Second, do error scores discriminate between differences in pilot ability? Third, are these scores sensitive to changes in the training program?

Reliability

Each quarter we would analyze the data from all checkrides stored to date to evaluate the stability of the mean error scores. Oddly, these means kept going down rather than merely being unstable. We then ran separate analyses grouping students chronologically, each group of 20 students representing roughly eight to ten weeks. No student was scored twice during this period. There was a high correlation between time and group mean scores ($r = -.98$). The results of an analysis of variance indicate a high reliability of this effect as shown in Table 1. This phenomenon has held true in five of the six checkrides currently developed.

This can be attributed to two factors. Pilots completing the training would presumably discuss the sequence of events back at their home unit to the benefit of those pilots yet to come. This was partially counteracted by the freedom of instructors to substitute malfunctions of the same general type for those pre-programmed. Secondly, as instructors became efficient in the role of training manager and more familiar with the checkride sequence, they became better able to train students in the skills measured by the automated scoring system.

TABLE 1. ANALYSIS OF VARIANCE OF MEAN TOTAL ERROR SCORES FOR CHRONOLOGICAL GROUPINGS OF STUDENTS ON HH-52A CHECKRIDE 1.

	N	$\bar{X}$	SD
Feb 74-May 74	24	1698.2	711.2
Jun 74-Aug 74	21	1449.9	629.2
Sep 74-Jan 75	22	1141.3	569.9
Feb 74-Apr 75	20	1053.8	388.3
All	87	1350.1	638.6
	df $^{3}_{83}$	F=5.51	$p<.01$

Validity

A comparison was made between a group of nine instructor pilots, who are responsible for determining standard operating procedures, and a group of 23 operational pilots on their annual instrument checkride. This comparison showed significant differences favoring the instructors in total error score ($p<.001$) and in 38 of the 58

individual parameter scores ($p<.01$). Of the twenty remaining parameters scores where no significant differences were found, all but two favored the instructors (Povenmire, 1974).

The objective scores did seem to differentiate between two groups known to have different levels of ability but the question remains as to whether higher error scores indicate progressive poorer overall performance. There can be no doubt that the simulator computer can measure what it measures with unfailing accuracy. However, scoring parameters were restricted to those that a well-qualified instructor would consider critical if violated. As previously mentioned, the number of scoring criteria were further restricted to allow all correct procedures to be scored equally. These two factors severely limited the number of data points that could be scored.

This brings up an important concept. Totally objective evaluation is possible only when limited to those performance criteria that can be expressed in quantitative terms. Much to the dismay of those who write behavioral objectives, judgmental behaviors cannot be quantified. Such major areas as troubleshooting strategy, reordering of priorities and coordination of flight crew can only be evaluated subjectively.

It is generally assumed that some correlation exists between ability to accurately perform standardized maneuvers and judgmental maturity and sophistication. To test this assumption, we asked the instructors to give a single subjective grade using a four point scale for the entire checkride. This was done prior to looking at the computer printout of error scores.

The correlation between total error scores and instructor grades on each current checkride is shown in Table 2. A perfect correlation would be -1.0 due to the fact that higher subjective grades indicated better performance and higher computer generated error scores indicated poorer.

TABLE 2. CORRELATION BETWEEN TOTAL ERROR SCORE AND SUBJECTIVE GRADES.

	Checkride	r
HH-3F	3	-.46
	4	-.56
HH-52A	3	-.63
	4	-.70

These correlations are somewhat lower than might be expected between two instructors subjectively grading the same performance (Povenmire, 1970; Koonce, 1974). They are also lower than those found by Knoop (1973) using a complex computed function of instructor pilot performance. Higher correlations might be achieved with future refinement discussed below.

Distribution of checkride scores in each grade category shown in Figure 1 illustrates the wide areas of overlap between various categories.

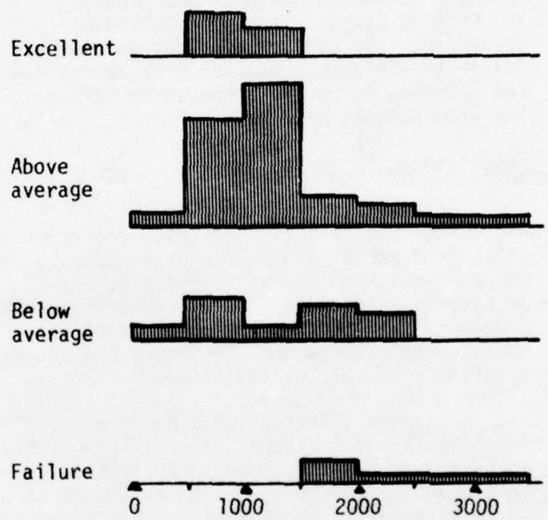

Figure 1. Distribution of checkride error scores in each subjective grade category.

Clearly, automated checkride scores cannot be the sole basis for passing or failing the final checkride. They can be used however to assist instructors in making pass-fail judgments. The greatest benefit of these objective scores involves their use in evaluating long-term stability of the training program.

Sensitivity

Beginning in January 1976, the instrument renewal course was changed by giving the automated checkride on the first flight

with no warm-up instead of at the end of the course. If performance was satisfactory, the emphasis shifted to emergency training. If the initial check showed weaknesses in instrument flying the instructor-manager continued to emphasize IFR procedures until the student performance met criteria. In either case, student performance on instruments and certain mandatory malfunctions met end-of-course criteria as before.

This change in the training sequence was immediately reflected in the mean error scores for both checkrides in both cockpits as shown in Figure 2.

DISCUSSION

Although limited in scope to mechanical piloting ability this automated performance scoring system was responsive to this major change in the training system. After each such change, however, a period of time is required to collect enough data to evaluate the effect. Data shown in the 1976 portion of Figure 2 were collected over an 18 week period.

Giving the recorded checkride first has given us a better indication of general operational readiness of Coast Guard pilots. It has also given the instructor-manager more information on student capabilities and therefore more flexibility in the conduct of training. Students and instructors alike have expressed nearly unanimous approval for this sequence.

On the other hand we have eliminated the ability to judge the effectiveness of the training program itself. Course requirements will not permit giving two fully automated checkrides during this one-week course. We are currently developing a very short checkride to be given at the end of the week, consisting of three maneuvers in which aircraft control is weighted very heavily as opposed to judgmental behaviors.

Refinements

Several areas for further development may provide more accurate descriptions of total performance. There is presently no differential weighting applied to the frequency and time out of tolerance on various parameters except by reducing tolerances at critical points. A student receives the same number of error seconds if he exceeds his cruising altitude by 100 feet as he does by going 200 feet below minimums on an ILS approach. Conversion to modified standard scores using standard deviations from an optimum (Koonce, 1974) seems promising as it

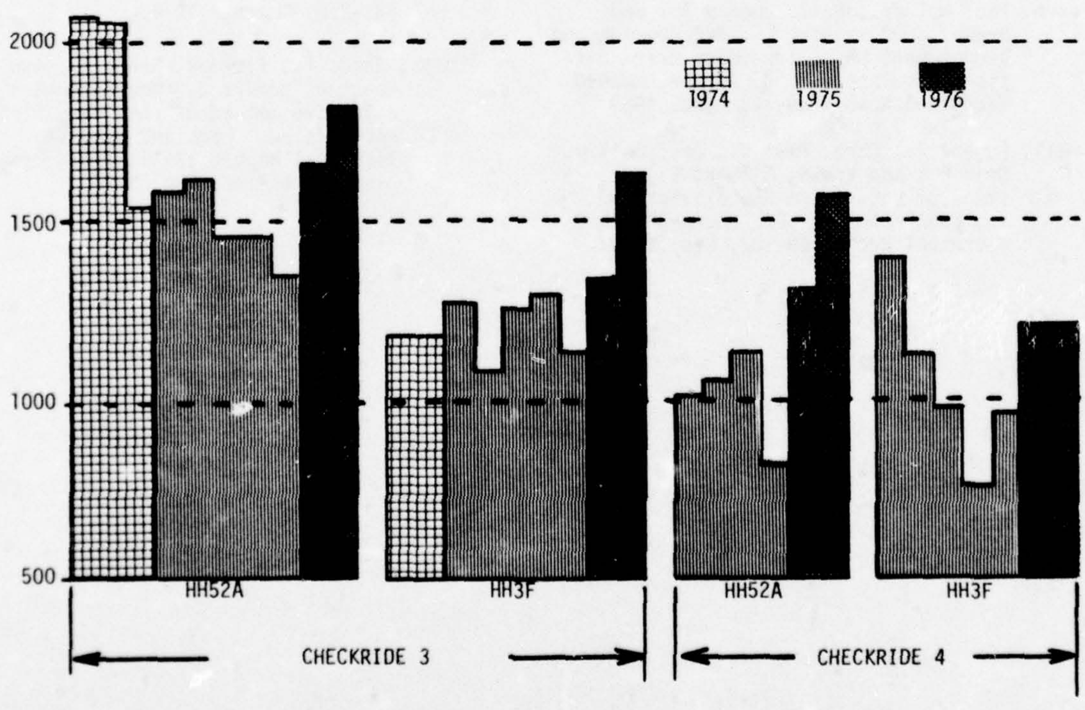

Figure 2. Mean scores for each ten classes in sequence for each current checkride.

tends to weight each parameter according to how much emphasis is placed on it by the sample of operational pilots. For this purpose, error scores would be more meaningful in terms of maximum deviation and root square error rather than time and frequency out of tolerance.

Greater reliability might be achieved in a more controlled flight profile than is possible here. In certain phases of pilot training judgmental behavior need not be evaluated. End-of-phase objectives can be fully described by performance on a series of standardized maneuvers where aircraft control parameters are most important.

CONCLUSIONS

Although we have relinquished more precise control of the test situation in favor of more realism in the test environment, results show that automated objective scoring is possible. As more data are collected adding increased stability,we should be able to evaluate instrument proficiency of Coast Guard aviators on a long-term basis. With the addition of a five minute checkride at the end of the course,we will regain an objective means for monitoring the training program itself.

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SIMPLIFYING THE MEASUREMENT OF COMPLEX SKILLS IN A TRAINING SIMULATOR

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INTRODUCTION

The Evaluation Problem

Student pilots must learn to operate a complex system in an unstable, frequently dangerous environment. These operational factors make stringent demands on an instructor pilot (IP) as he evaluates student pilot (SP) performance in an aircraft. The IP must monitor SP behaviors, unsafe performance conditions, and dangers in the airspace. Observations in all relevant areas of performance must be remembered or recorded and then used to arrive at a meaningful evaluation of performance skill.

Clearly, the IP must process large quantities of information. As training tasks become more complex or dangerous, demands on the IP tend to increase and IPs tend to be less and less able to adequately process all the essential information. As the information processing load increases, the integrity of safety procedures, training effectiveness, and evaluation methods may be compromised.

Evaluation Methods in Pilot Training

After more than 30 years, rating scales remain the basic IP evaluation method. Rating scales are still used because they best meet the needs of training management and the operational user - the IP - without intruding seriously into the IP's operational tasks (Koonce, 1974).

As currently used, however, rating scale methods are marginally adequate for evaluations in training research and development because most observations using them lack sufficient discrimination; i.e., the observations tend to accumulate on two, or at best three points in the rating scale (Knoop & Welde, 1973). To make IP observations more discriminating in training research and development, extensive observer training and quality control programs must be developed and carried out (Horner, Radinsky, and Fitzpatrick, 1970; Koonce, 1974). This is a continuing and cumbersome process during the design and conduct of a study. Furthermore, no practical alternative to IP ratings of airborne performance has been readily available.

The increasing sophistication of flight simulators allows greater opportunity to utilize objective data recording and processing methods. When such simulators are used in both training and research, it is important that the objective measures be reliable, readily accessible, simply computed and, most importantly, meaningful to each user - IP, student pilot, and researcher.

There are a variety of objective measures that can be used with a flight simulator. In this study, objective measures were divided into two broad categories: exact and summary indicators. An exact indicator was a measure easily observed at one or a few points in the sequence of events which comprise the profile of a training task. Most exact indicators used in training research are not well suited for general applications because they are not usually derived from theoretical or general training requirements. Instead, they are selected or developed to reveal potential differences in performances which will answer some specialized research question. When that specialized need has been satisfied, all further interests in the measurements are dropped (Koonce, 1974).

By contrast, summary indicators are very popular in most training research applications. Selected to reveal general trends or overall differences, a summary indicator was a global measure computed continuously or from a large number of discrete observations made throughout a single performance. Summary indicators have been criticized because they are usually insensitive to the effects of particular events or skills in a performance (Knoop and Welde, 1973), and because they are usually based on massive quantities of data with no definitely specified relationship to the evaluation problem (Christensen and Mills, 1967; Koonce, 1974).

The purpose in this study was to investigate exact indicators of particular skills or events that could be used with a performance state evaluation model to simplify objective

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measurement procedures in pilot performances; in short, to reduce excessive detail while not being uniformatively general (Youtz and Ericksen, 1947). A step in the solution of this detail versus generality dilemma would be achieved if a general set of exact indicators were derived from a theoretical and/or training requirements analysis, and if such measures were empirically shown to carry sufficient information to evaluate performances in a training research effort. The research hypothesis was that a set of exact indicators would successfully replace a global summary indicator typically used in pilot training research.

APPROACH

The Performance State Evaluation Model

Movements of an aircraft through space and time (i.e., the flight path) can be described with values from several variables such as altitude, heading, airspeed, pitch, and power. To accomplish his mission, a pilot must control the movements of the aircraft by using information from some of these variables to make changes on others. Any set of values on these variables becomes a system "state." A state, then, is the complete set of variables needed to describe the entire performance of the pilot and the aircraft at any instant in time (Etkin, 1972). To evaluate a pilot's performance, values are observed in one or more states and if they meet certain requirements, the performance is assigned an appropriate score or mark to indicate the level of achievement.

A review of measures used in previous pilot training research produced three possibilities which might be effectively used as exact indicators. These three measures were the range, the maximum deviation from the standard, and performance time. The range and maximum deviation were established in World War II as objective measures of instrument flying skills (Hagin, 1947). Since that time, many researchers have validated the utility of these two measures.

In parallel research during World War II, performance time was also studied (Miller, 1947). Performance time appeared promising as a simplifying metric inasmuch as it was also found to be a good indicator in two recent studies. In a training experiment, Brecke, Gerlach, and Shipley (1974) found that differences in means and variances on performance time discriminated between treatment groups. In another study, Knoop and Welde (1973) obtained 87 different objective measures from aircraft data as well as ratings from pilots and student pilots on the same performances. Of the 87 different measures, 7 or 8% were time measures. When correlated with the ratings, 11 or 14% of the 77 significant correlations (.05) involved the time measures.

Performance Time Algorithm

To empirically study time and deviation measures, a situation was selected in which students in undergraduate pilot training were learning a complex instrument flight task, the Vertical S-A, in a simulator (USAF ATC Syllabus, 1975). Performance state criteria were analytically determined for seven "states" of the Vertical S-A by Brecke and Gerlach (1972). Shipley, Gerlach, and Brecke (1974) derived flight path standards and performance times from these criteria. In the present study, an algorithmic, performance state evaluation model was developed for the maneuver and performance times and deviations from the standard flight path values were then studied as potential indicators of skill in three empirical investigations.

Since it is impossible for a performance to deviate significantly from standard times and still satisfy all other performance criteria throughout an entire flight, performance times can be used with deviations from flight path standards to simplify measurement and evaluation procedures for many maneuvers. In the algorithmic model, if total time is not within given tolerances, some state or states must contain errors; these errors will be reflected as deviations from the standard. The state or states which contain the errors can be quickly located by examining the performance time for each state. For a state that fails the time test there are three possible outcomes: (a) if the entry conditions to that state deviate significantly from the standard, at least some source of the error will be in the <u>preceding</u> state or states; or, (b) if the entry conditions for a state are within the given tolerances, the sources of the error must be located <u>in that state</u>; and, (c) if the end point deviations are out of tolerance, the <u>following state</u> should also contain information about the pilot's performance.

Data for the three investigations were obtained from an earlier experimental study by Brecke (1975) in which measures of time, airspeed, heading, vertical rate, pitch, power, and altitude were automatically obtained, at a sampling rate of one second, from performances of the Vertical S-A maneuver in a flight simulator. (Readers interested in more detail about the experiment or the data should consult AFOSR Technical Reports #50430 and #60229 by Brecke (1975) and Shipley (1976) respectively.)

INVESTIGATION I

The first investigation was carried out to compare "standard" time values for the Vertical S-A states with observed performances from two experienced pilots. The purpose was to discover whether or not the performance state evaluation model would reveal any significant differences among the performances of these two pilots. If the model detected significant differences among performances of experienced pilots, it should also make similar discriminations among performances of student pilots. Such discriminations are essential to effective evaluation in regular training and in experimental research on the effects of training methods.

Method

Two experienced pilots performed a sequence of 12 trials, 6 each, on the Vertical S-A in a flight simulator according to procedures described by Brecke (1975). Two trials of one pilot's performances were not included in this investigation; his first trial was a descending rather than a climbing Vertical S-A and data from his last trial was unusable because of a data recorder malfunction.

Procedures

Performance time and maximum altitude data were obtained from computer printouts of these performances and the means and variances were then computed for each pilot's data on total time, times for the seven performance states, and maximum altitude. Deviations of observed from corresponding standard values were also computed and used as the basis of tolerance limits in subsequent analyses of student performances.

Results

The means and variances of the performance times revealed three significant differences. There were two significant differences (.05) between means: a difference of 14.35 seconds on total time and a difference of 10.08 seconds on the time for the climb state. Finally, the variances were not homogeneous for time in the third transition state.

INVESTIGATION II

The second investigation was carried out to determine whether total performance time and/or maximum altitude discriminated between performances of treatment groups in a training experiment. An a priori prediction, that differences among maximum altitude variances would discriminate among treatment group performances, was based on a training requirements analysis (Brecke and Gerlach, 1972; Gerlach, Brecke, Reiser and Shipley, 1972) and on the outcomes of a prior experiment (Brecke, Gerlach and Shipley, 1974).

Method

Thirty-nine student pilots were randomly assigned to one of five groups. Members of four experimental groups studied the objectives and different preflight instructions on how to perform the Vertical S-A; members of a control group studied only the objectives. After each subject had studied his assigned materials, he performed a sequence of six trials on the Vertical S-A according to procedures described by Brecke (1975).

Procedures

Total performance time and maximum altitude values were obtained from the Brecke data. Total performance time values were analyzed with a two between- one within-subjects analysis of variance; repetition of performance trials on the Vertical S-A maneuver was the within subjects variable. Dunnet's method (Myers, 1966) was used to compare the means of the treatment groups with the means of the control group.

It was hypothesized that subjects in groups given experimental instructions would exhibit less variability among their performances at maximum altitude than subjects in either the control group or the groups given current instruction. To test this hypothesis, F-ratio tests for differences between group variances were used rather than tests for differences in means, i.e., ANOVA or t-tests (Winer, 1972).

Results

Total time. In the ANOVA on total time, there were significant main effects for type of instruction, number of response items in the instructional material, and performance trials. A significant interaction was also found between number of response items and performance trials. There were no significant differences on Dunnett's tests between any treatment group and the control group.

Maximum altitude. As predicted, the comparisons among the treatment groups' variances were significant on the maximum altitude measure. At maximum altitude, the variances of the two groups that received experimental instructions were significantly smaller (.05) than the variances of the control group and the two groups receiving current instructions. The control group variance was not significantly different at maximum altitude than the variances of either group receiving current instruction.

Summary

To summarize the results of the first two investigations, performance times and maximum altitude discriminated among the performances of both individuals and groups. To the extent that the observed variations in performance time and maximum altitude reveal variability in the pilots' pitch and power control skills, these findings provide strong support for the hypothesis that exact indicators could be used as alternatives to summary indicators. In the third and final investigation, this hypothesis was examined by comparing the relationship between values on the two types of indicators.

INVESTIGATION III

In this last investigation, the hypothesis was that a set of exact indicator values would predict values of a summary indicator. If scores from a summary indicator in the Brecke (1975) data could be predicted with scores from a set of exact indicators, evidence would be obtained to support a recommendation to use the exact indicators in place of the summary indicator. A multiple regression analysis was used to test this hypothesis.

Method

To evaluate the results of his experiment, Brecke (1975) used a summary indicator of variability in pilot performances called error amplitude. Error amplitude scores in Brecke's study were computed with procedures described by Shipley, et al. (1974). Conceptually, error amplitude is a normalized root mean square measure obtained with the deviations of each observation from the corresponding standard and a set of tolerance limits for each parameter. In the present investigation, error amplitude scores from Brecke's data were used as the criterion variable.

The exact indicators used as variates in the regression analysis were deviations from the standard on the performance state times, total time, and maximum altitude. Three combinations of performance state times were also included as variates in the regression design; these combinations were (a) the sum of the first three performance state times; (b) the sum of the last three performance state times; and (c) the sum of the times for all seven performance states. These sums were included in the design to test whether gross measures of time would be better predictors than more specific measures. Prior experience measures included as variates in the design were total hours as a pilot, flying time in undergraduate pilot training, total hours in the T-4 simulator, and number of minutes to complete the instructional materials in the Brecke (1975) experiment.

Procedures

A set of 30 correlation matrices formed the basis of the regression analysis: one matrix for each of six performance trials across the five groups in Brecke's experimental design. The correlation coefficients were averaged over the five groups, after a Fisher's r to Z transform (Hays, 1963), and the means were then converted back to equivalent r values. The result was a set of six matrices of average correlations, one matrix for each trial. Finally, each of these matrices were submitted to a sequence of two stepwise regression analyses. The first analysis was based on the average correlations from the exact indicators and the sums; the second was based on the average correlations from the exact indicators, the sums, and the prior experience measures.

Results

In the results of the regression analyses, support would be obtained for the hypothesis if two criteria were satisfied: (a) if a small set (4 to 6) of the 12 exact indicators were consistently selected in the regression equations; and (b) if equations using these consistently selected indicators would account for a substantial proportion of the variance (50% or more) in the criterion.

The outcomes of the regression analyses confirmed the hypothesis. It was found that, of 16 possible indicators and experience measures, a set of 9 were frequently selected in the regression analyses. Various combinations from this set of nine were selected in equations of just five variables for each of the trials and these five variable equations accounted for 62% or more of the variance in the summary indicator, error amplitude.

The type of variable selected in these equations with five variables changed across the trials. For the first two trials, prior experience and combined times were predominant in the equations. By the last two trials, the exact indicators were predominant.

As measures of learning over trials, the summary indicator and the exact indicators were compared by making a plot of the means of each variable across the trials. It was found that deviations from maximum altitude exhibited virtually the same learning trend over trials as error amplitude (r = .98).

These results provided convincing evidence to support the hypothesis that in the Vertical S-A, exact indicators could be used to replace a summary indicator.

DISCUSSION

In these analyses, exact indicators were found more sensitive to the effects of different experimental treatments than a summary indicator. In addition, when used alone, a set of exact indicators were found to account for moderate (34%) to large (82%) proportions of the variance in a summary indicator. These findings are provocative because they suggest that a few well chosen observations, i.e., fewer data points, can be used to obtain evaluations superior to those obtained from typical summary indicators based on many data points.

The results of these investigations also support the use of a performance state evaluation model. Performance times and deviations from maximum altitude were found to discriminate precisely between both individual and group performances and to identify the sources of errors within a given individual performance. It is interesting that performance time for the transition from climb to maximum altitude was consistently found among the predominant predictors in the regression analyses. In previous research, Gerlach, et al. (1972) predicted, on the basis of a theoretical and a training requirements analysis, that this location was the most likely source of student performance errors in the Vertical S-A. Coupled with the demonstrated sensitivity of deviations from maximum altitude, it is clear that the evaluation model could be effectively utilized for performance of the Vertical S-A in a flight simulator.

For the operational user, these findings suggest that exact indicators can be used to replace summary indicators and also global ratings. Maximum altitude, an example of an exact indicator in the Vertical S-A, was found to carry nearly all the information given by error amplitude, a summary indicator. Since maximum altitude in the Vertical S-A occurs at a well defined point, IPs could easily observe it and use its value to replace a global rating. The dilemma of excessive detail versus uninformative generality in pilot training measurement and evaluation can be given a workable solution to the extent that similar values and their locations can be derived for other pilot training maneuvers.

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MAINTENANCE READINESS THROUGH EFFECTIVE SIMULATION TRAINING

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Educational Computer Corporation

INTRODUCTION

Prepare maintenance technicians to be job-ready. That is the goal of maintenance training. As it exists today, it works with varying degrees of proficiency. Much of it could work better if all the necessary training aids and devices were available to the training facility: Audiovisual devices, Maintenance Training Units (MTU's), Actual Equipment Trainers (AET's), Simulation Models, etc. How and what devices are selected for a particular application is an exercise in itself, and as such is often the reason why many training facilities don't have the necessary training aids. Effort is spent evaluating and determining which or what device best suits a particular need. In the meantime the training facility is making do with whatever it has.

This is the case with maintenance simulation. Simulation is fairly well accepted for operator training, especially in flight training. It has its obvious advantages--cost savings, safety, condensation of time, opportunity to practice procedures which occur only during rare and critical situations, etc. There is much debate over how many degrees of motion, how to provide the motion, and what fidelity should be provided. But whatever is required or desired is available - at a price. Simulation in other areas has been slow to be accepted, especially in maintenance training. One reason is that it is not always applicable to the training requirement, but in those instances where it is applicable, too often the reasons for not using it are not objective. It is often accepted conceptually, but it is something new, it is different, and not everyone who has the requirement is willing to make that step to simulation for maintenance training. Many people are studying the problem.

They ask how much fidelity; what is the transfer rate; what is the retention rate; how does it compare to existing processes; is it better than using maintenance training units or actual equipment trainers; how best to evaluate its applications? All valid questions, but the questions continue to outnumber the answers. Some of these people appear to be making the study of the problem an end in itself.

An attempt to justify simulation in maintenance training will not be made here; however, some studies which have been conducted with the particular device discussed in this paper are referenced: [1], [2], [3], [4], [7]. The main intent of this paper is to describe the use of a simulator in maintenance training at a facility that had a need and took the necessary steps to acquire it. That facility is the Marine Corps Air Station, Cherry Point, North Carolina, NAMTD 1006, where AV-8A Organizational and Intermediate Maintenance Activity training is conducted.

BACKGROUND

The AV-8A (Harrier) Aircraft is manufactured by Hawker-Siddley Aircraft, Ltd., in the United Kingdom. It is a high-performance attack jet aircraft with many complex internal operating systems. The aircraft is operational with the United States Marine Corps, Marine Air Group 32(MAG-32).

In early 1973, maintenance training for the AV-8A was being conducted at the Marine Corps Station, Beaufort, South Carolina. The programs of instruction for most of the courses were still in a developmental stage. Training was being conducted with only a very limited number of training aids. These were primarily static display panels and a few film transparencies. They allowed the instructor to provide the student with chalkboard talks and information about the various systems and their operation. The instructor was able to demonstrate limited systems operation and he could only discuss the theory of fault isolation procedures. If and when he had test equipment available, he was able to demonstrate calibration, checkout, and test maintenance.

The school was having the usual contest with squadron maintenance trying to acquire test equipment for training use. As is typical the school was usually on the short end. In those labs where they did have test equipment, they had the also typical problem of maintaining and calibrating it. When their test equipment was sent to the calibration lab, it received the lowest priority, and as a result there were long periods of time when the class would be without test equipment. When it was available in the classroom there was instructor reluctance to allow the student free use of it. The student had to be continually monitored. His inexperience with using the equipment generally resulted in its rapid deterioration. Acquisition

of a maintenance training simulator would eliminate this problem.

A number of simulation models which could be used in the various courses were proposed by Educational Computer Corporation (ECC). The models were designed to satisfy training requirements imposed by the instructional staff and be able to be used within the existing courses and those that were yet to be developed. The use of the simulators would increase the overall effectiveness of the training by allowing the instructors to cover each system more thoroughly. The simulation models would be designed to include the necessary test equipment in each particular application and thus eliminate the requirement for the actual special support test and calibration equipment required. The student could be allowed free use of the models for practice without fear of damage.

In addition, the school was under pressure to begin its training. Expediency in delivery of equipment was critical. Subsequently, nine simulation models which would be designed to support the training requirements in selected courses of instruction, were proposed by Educational Computer Corporation. A contract was signed in May of 1973. In January 1974 the nine models were delivered and accepted. The mainframes had been delivered prior to that time. In approximately 28 weeks after contract the school had its simulations.

Originally, nine simulation models of the operating AV-8A Aircraft Electrical Systems were proposed. These would be used to support organizational level maintenance training at one site which was later transferred to MCAS Cherry Point, North Carolina. The simulation models would enable the instructor and/or the student to locate, operate, calibrate, test, and simulate the replacement of aircraft line replaceable assemblies. The nine models proposed were:

- Electrical Power Supply - AC-4KVA
- Power Supplies - DC - 4KVA
- Power Supplies - AC/DC 12KVA
- Gas Turbine Starter/Auxiliary Power Unit
- Power Plant Instrumentation
- Fuel System 1
- Fuel Panel 2
- Auto Stabilization
- Centralized Warning System

The use of these simulation models subsequently led to the ordering of eighteen additional simulation models, two of which, the "Air-Data Computer" and the "Engine Life Recorder" were designed for Intermediate Maintenance Activity (or "I" level) training.

SIMULATOR DESCRIPTION

At this point it would be well to describe what the simulation models are. The models mentioned are components of a system manufactured by Educational Computer Corporation. Detailed descriptions of the development and design of a simulation model are available in other papers: The Educational Computer Corporation Approach to Hands-On Maintenance Training, Siecko [5]; Effective Training Through Simulation--Now, Siecko and Breslin [6]. Figure 1 provides a description of an EC II-LP and its various subcomponents. Briefly, it is a main frame which houses a computer which is used to drive the display panel, the projector and the meter as required. The control console provides a means whereby the overall status of the simulation display panel can be changed; for example, from a normal configuration to a malfunctioning configuration, or requirement for various checkout procedures or a checkout of a system which contains a malfunctioning component. The display panel is the central focus of the simulation model in that it contains a facsimile rendering of the system or systems being simulated. This panel may also contain hardware as is required to facilitate the simulation. Figure 2 is a picture of the simulator with a simulation model inserted. Figures 3 and 4 depict the desk-size version of the EC II.

What is unique about these simulators is that they are programmable and the point of interaction with the operator (student or instructor) is the two-dimensional panel which contains a rendering of the prototype system or device being simulated. This panel may contain lifelike or actual hardware depending upon the training application. This, in turn, is supplemented with a random access slide projector to provide cues, symptoms, instruction, queries, and so forth, to the student or directions to the instructor. Operation of the simulation model is performed directly upon the panel. For example, the student or instructor would operate or perform a checkout procedure of a radar or navigational control system just as he would in real life. Control of the simulation is managed by an internal digital processor.

In addition to the panel I/O, there is a control panel which directs the status or condition of the simulation. This status can take many forms. One is that of a normal condition--where all operations reflect the system in a normal or operating state. Other conditions can be various malfunctioning states of the simulated system. Under these conditions, all indicators, components, and tests depicted or made on the panel behave as they would in the real world when the system has a specific malfunction. The device can accurately reflect selected equipment problems

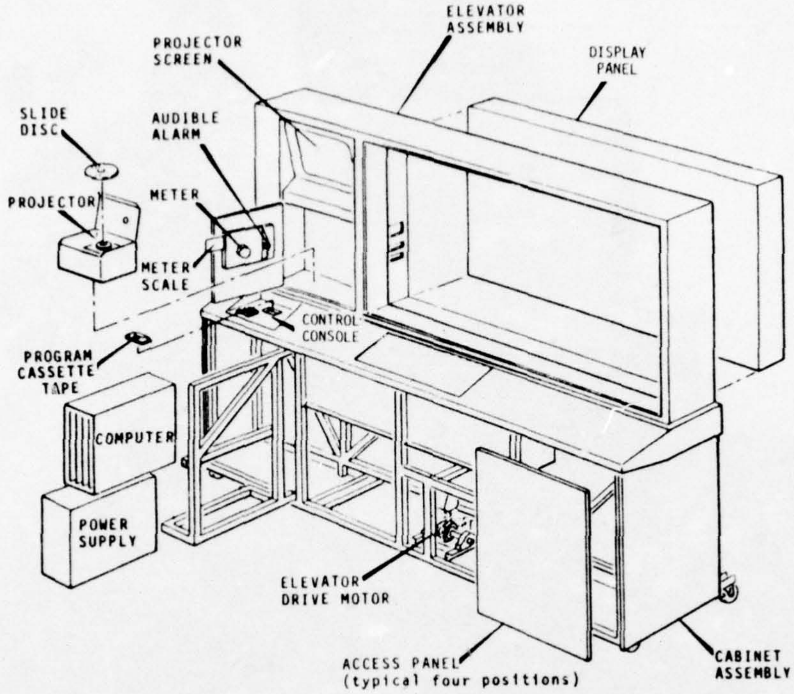

Figure 1. Exploded View of EC II-LP

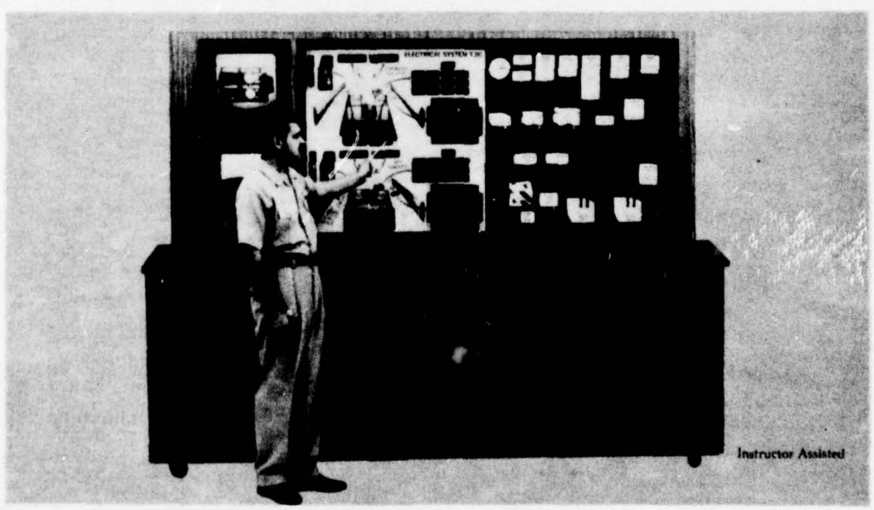

Figure 2. EC II-LP

Figure 3. EC II

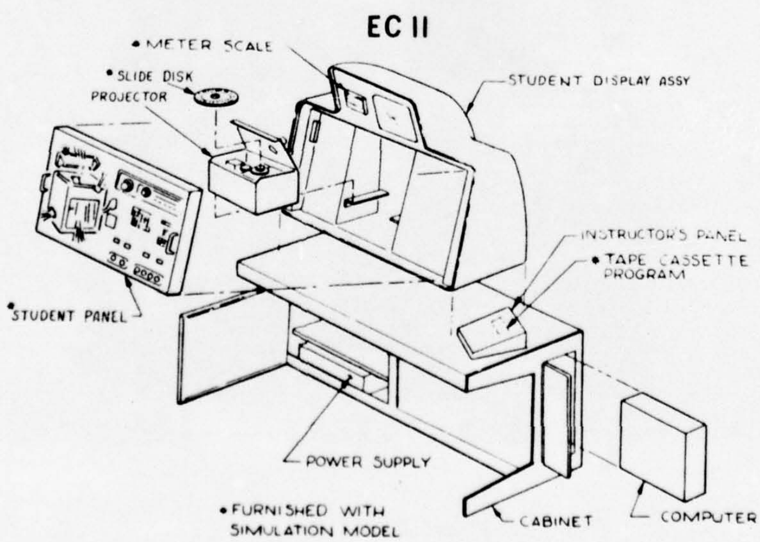

Figure 4. Exploded View of EC II

and a student can repeatedly practice his diagnostic skills until he reaches some required proficiency level.

The operation of the simulation can be either directed or random. This is an option of the simulation designer and is dependent upon the governing factors within the training system. These factors are uncovered during the design of the training system. Most often, when troubleshooting has been selected as one of the learning criteria, the student has been relegated to the study of flowcharts, OJT, and reliance on his ability to apply his theoretical understanding to the real world. This device provides simulated practice in troubleshooting and diagnostics in a controlled learning environment.

The programmability of this type of simulator provides it with unlimited potential. For example, while the panel remains unchanged, the control console or a separate program can request a condition which is fully instructional-introducing the student to the simulated system and diagnostic techniques. Another condition can be such that the student is left to his own capabilities-without instructional control. The program can be constructed to monitor the student as much as is desired. Modification of the simulation model is inherent within its design. The program can be modified inexpensively and at any time. A modification of the panel generally involves only a patch to change artwork and/or the addition or removal of some panel component.

The device is built by Educational Computer Corporation in various forms. One model is produced in a desk-size configuration (the ECII). A second is a larger version used for classroom demonstration (the EC II-LP).

APPLICATION OF SIMULATION MODELS

The NAMTD 1006 receives most of its students directly from the Naval Aviation "A" School, Memphis. An entering student is normally assigned to one course. After completion he then receives on-the-job training (OJT) at the squadron and only after his Work Center Supervisor deems he is capable of unsupervised activity does he receive his MOS rating. He may, however, be sent back to the school for other speciality training and thus have more than one MOS.

Courses at the NAMTD range from four weeks for the Aircraft Engine Mechanic Organizational Course to 13 weeks for the Electrician Organizational Course. The school is authorized to teach 26 courses, but only 13 courses utilize the simulation models, of which they have 27 (See figures 5, 6, 7, and 8 for pictures of the display panels for some of these models.):

- Nose Wheel Steering
- Head-Up Display System
- 4KVA DC Power Supply
- LAU-7/A Guided Missile Launcher
- Engine Fuel System
- CNI (Navigation)
- Landing Gear
- Wheel Brakes and Antiskid
- No. 1 Hydraulic Power Supply
- Wing Flaps
- Cabin Air Conditioning
- Armament Control System
- Gas Turbine Starter/Auxiliary Power Unit
- 4KVA AC Electrical System
- 12KVA AC/DC Electrical System
- No. 2 Hydraulic Power and Ram Air Emergency Supplies
- CNI (Communications)
- Air Brake
- No. 1 Fuel System
- No. 2 Fuel System
- Centralized Warning System
- AV-8A Autostabilization System
- Power Plant Instrumentation
- Baseline 800 Attitude and Heading Reference System
- Baseline 800 Weapon Aiming System
- Air Data Computer
- Engine Life Recorder

Because the EC II-LP simulator main frame is a standard item and all of the simulation models are interchangeable, the school requires only nine simulator main frames to support its 27 different simulation models. The main frames are portable and are moved to the classroom as they are needed, depending upon course scheduling and student flow. The appropriate model-display panel, program, and slide disk are then inserted and the simulators are ready.

All of the simulation models are programmed for normal operation status and contain malfunctions selected to intensify the training requirements. All courses which utilize the simulators reflect their use in their programs of instruction.

The following is a list of courses taught at the NAMTD 1006 that utilize the simulator and the simulation models used in each course.

__ Pilot's AV-8A FAM: A seven-day course which utilizes approximately 20 of the available models.

__ Enlisted AV-8A FAM: A four-day course which uses fourteen of the models.

"O" - Level Maintenance AV-8A

__ Electrician Organizational Course: A six-week course using nine models

primarily designed for electrician training:

- Gas Turbine Starter/Auxiliary Power Unit
- 4KVA DC Power Supply
- 4KVA AC Electrical System
- 12KVA AC/DC Electrical System
- Centralized Warning System
- No. 1 Fuel System
- No. 2 Fuel System
- Power Plant Instrumentation
- AV-8A Autostabilization System

Five hydraulic/electrical models:

- Wing Flaps
- Landing Gear
- Wheel Brakes and Antiskid
- Air Brake
- Nose Wheel Steering

One Environmental/Electrical:

- Cabin Air Conditioning

One INAS/Electrical

- Baseline 800 Attitude and Heading Reference System

__ Armament Organizational Course - utilizes two panels:

- Armament Control System
- LAU-7/A Guided Missile Launcher

__ Environmental Organizational Course - utilizes one panel:

- Cabin Air Conditioning

__ INAS (Initial Navigation Attack System) Organizational Course utilizes 3 panels

- Baseline 800 Weapon Aiming System
- Baseline 800 Attitude and Heading Reference System
- Head-Up Display System

__ Hydraulics Organizational Course - utilizes seven panels:

- No. 2 Hydraulic Power and Ram Air Emergency Supplies
- Wing Flaps
- Landing Gear
- Wheel Brakes and Antiskid
- Air Brake
- Nose Wheel Steering
- No. 1 Hydraulic Power Supply

__ CNI (Communication, Navigation and Identification) Organizational Course - utilizes two panels:

- CNI (Navigation)
- CNI (Communications)

__ Aircraft Mechanic Organizational Course - utilizes one panel:

- Engine Fuel System

Intermediate Maintenance Activity (IMA) AV-8A

__ Air Data Computer IMA Course - utilizes one model:

- Air Data Computer

__ Engine Life Recorder IMA Course - utilizes one model:

- Engine Life Recorder (This course will be discussed at some length in the text of this paper.)

__ Head-Up Display (HUD) IMA Course - utilizes part of the "O" level "Head Up Display System" model in a FAM fashion for teaching symbology, modes of operation, and a system overview.

INTERMEDIATE MAINTENANCE ACTIVITY

The system maintenance plan describes the overall maintenance structure for each system in the AV-8A and states which Line Replaceable Units (LRU) exist in that system. At the Organizational Level (O-Level) maintenance the technician is required to perform a systems checkout to the line replaceable level and isolates and replaces faulty LRU's. For each LRU an individual maintenance plan exists and the Intermediate Maintenance Activity (IMA) or I-Level maintenance technician is responsible for this activity. Intermediate maintenance activity requires that the LRU be checked, repaired, and tested to the Sub-Replaceable Assembly (SRA) level and then the technician repairs the SRA, or he identifies the faulty component and the SRA is sent to the mini-lab for component replacement. Two of the simulation models listed above, the "Air Data Computer" and the "Engine Life Recorder" are IMA models.

These two simulation models were just recently received by the NAMTD 1006: the "Engine Life Recorder" (ELR) and the "Air Data Computer" (ADC), and will be used for I-level training. At the time of this writing the course had not yet been completed for the Air Data Computer; however, five classes have used the simulation model for the ELR, and the sixth was in progress. Classes usually contain four students each. Before the school had the simulation model, students received lectures in operation, test and checkout procedures for ELR Intermediate Maintenance Activity. However, no practical exercises were available. Any practical knowledge gained had to await OJT at the squadron level.

The Engine Life Recorder (ELR) "provides a visible means of indicating the used life of a gas turbine engine. The recorder is connected to the thermocouples in the jet pipe and the voltage produced by the thermocouples is used to drive a numerical display in the recorder, the rate of count being related to engine temperature." (A.P.112G-0132-1)

The simulation model of the Engine Life Recorder is designed primarily to provide a student with an individualized hands-on medium for operating and troubleshooting the ELR as depicted on the display panel. Figure 9 is a picture of the Engine Life Recorder display panel. It also allows the instructor to demonstrate the unit to a group of students. Through inclusion of applicable supporting test equipment, both normal and malfunction operations in an Intermediate Maintenance Activity can be simulated. The display panel allows the student or the instructor to make operational checks, troubleshoot, fault isolate, and make simulated equipment adjustments and calibration checks. The panel provides views and test points to allow these activities. Simulated on the panel is an ELR Test set, a power supply, a VOM, a stop watch, and a DANA digital voltmeter. Using the simulated ELR components he can perform the checkout, test, calibration and troubleshooting procedures specified in the technical manual (A.P. 112G-0132-1).

Especially important to the learning situation is the fact that the student can practice making adjustments to the trim pots which regulate the counters. For example; the test procedures require that certain standard conditions be established for the thermocouple inputs and the technician must regulate particular trim pots to bring the count within specification. He does this using the stopwatch and observing the ELR digital counter readout. This procedure is done on the simulator just as it would be in actual practice.

Another advantage of the simulator is that it is programmed to inform the student when he errs. It tells him where he can go for additional information. He is made aware of unsafe practices such as are warned against in the manual. Because it is simulated and under program control the test equipment never needs calibration. For example; if he uses the ohmmeter with power applied to the unit, he doesn't destroy a VOM or DVM.

In addition to providing practice in test and checkout procedures for the ELR IMA student technician this model also can depict the following malfunctions:

- Diode D24 open
- V T 9 open
- Relay C on board 3 inoperative
- Zener diode Z20 on board 3 open
- Amplifier A1 on board 1 fails
- Trim pot RV4 on LAW unit open

These malfunctions are entered through the control console keyboard by simply pressing their identifier code and hitting the enter key. When that is done all observable indications on the display panel (voltage checks, counts, etc.) react as they would on the actual equipment. The malfunctions programmed for this simulation model were selected on the basis of their commonality and frequency of occurrence determined at the overhaul facility.

Thus, when the student completes his training using the simulation model, he has already had practice in going through a full checkout procedure with equipment replicated as being in the normal state and checkout procedures where various malfunctions occur during the checkout. He gets real, life-like practice in "tweaking" the ELR to bring it into specification and he also simulates replacement of various representative components. He could not get this with actual equipment in the lab. Thus, when he leaves the school for an assigned squadron, he already has a basic useable maintenance skill.

CONCLUSION

In its Organizational and some Intermediate Maintenance Activity training the school relies almost entirely on use of its simulation models. When one tours the NAMTD 1006 Training Facility, there is no test or calibration equipment in the classes using the simulators.

The NAMTD 1006 had a critical training problem: To prepare maintenance trainees for the squadron, but they were without the necessary facilities. In order to meet their objective they took a pragmatic look at what was available to solve their problem. They made their decision to select simulation equipment and followed through with it.

Evaluation of the simulators was not their intent - preparing their students to be as job ready as possible was, and that is what they did. Their graduates can actually perform when they arrive at their assigned squadrons.

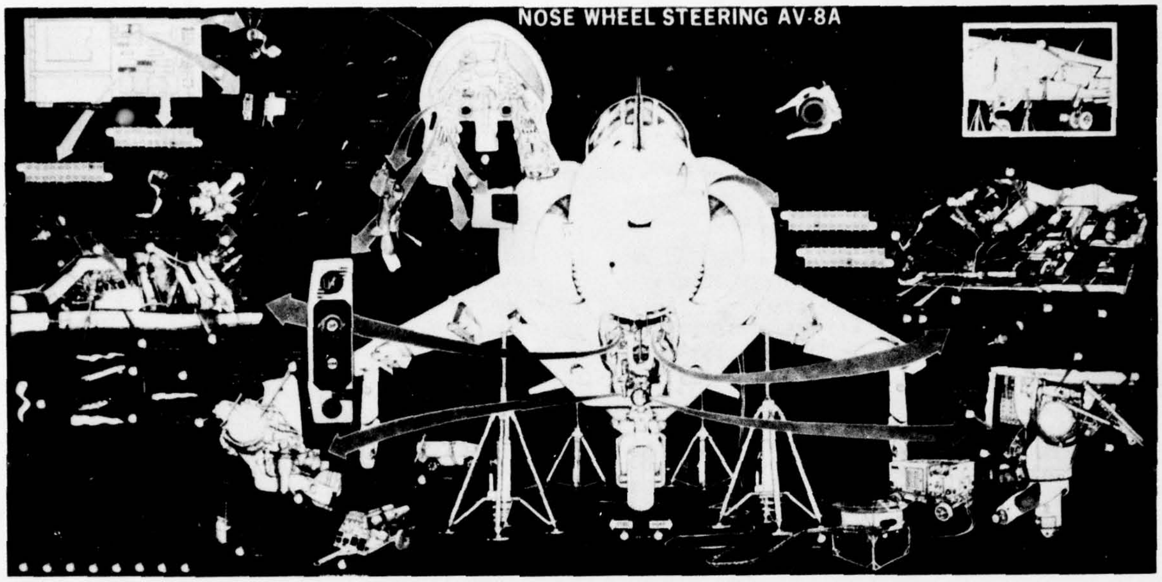

Figure 5. AV-8A Nose Wheel Steering Display Panel

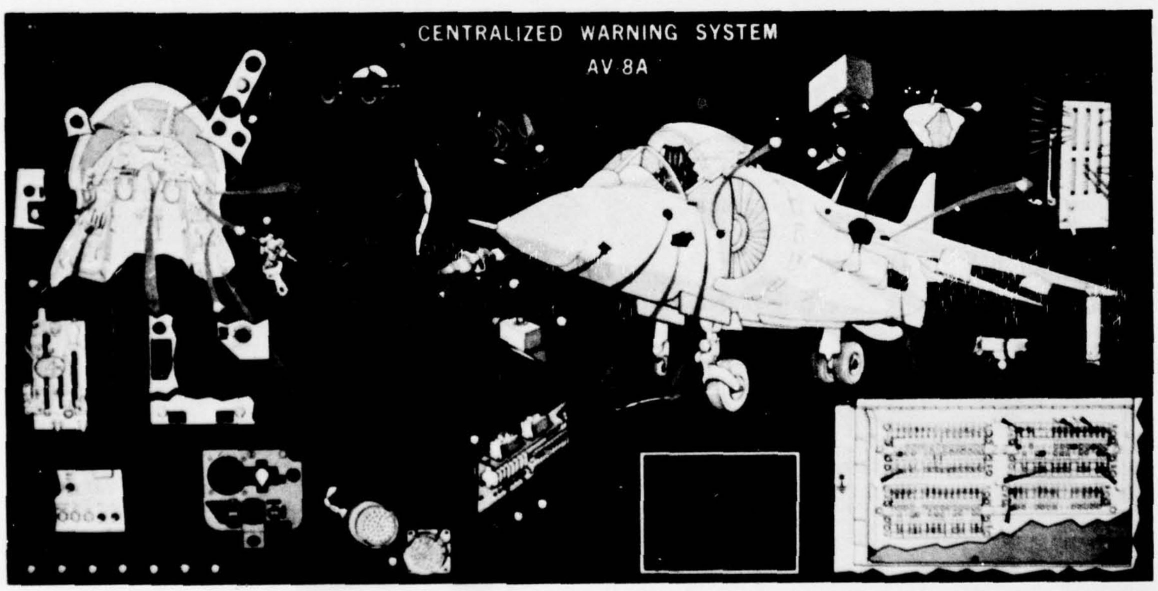

Figure 6. AV-8A Centralized Warning System Display Panel

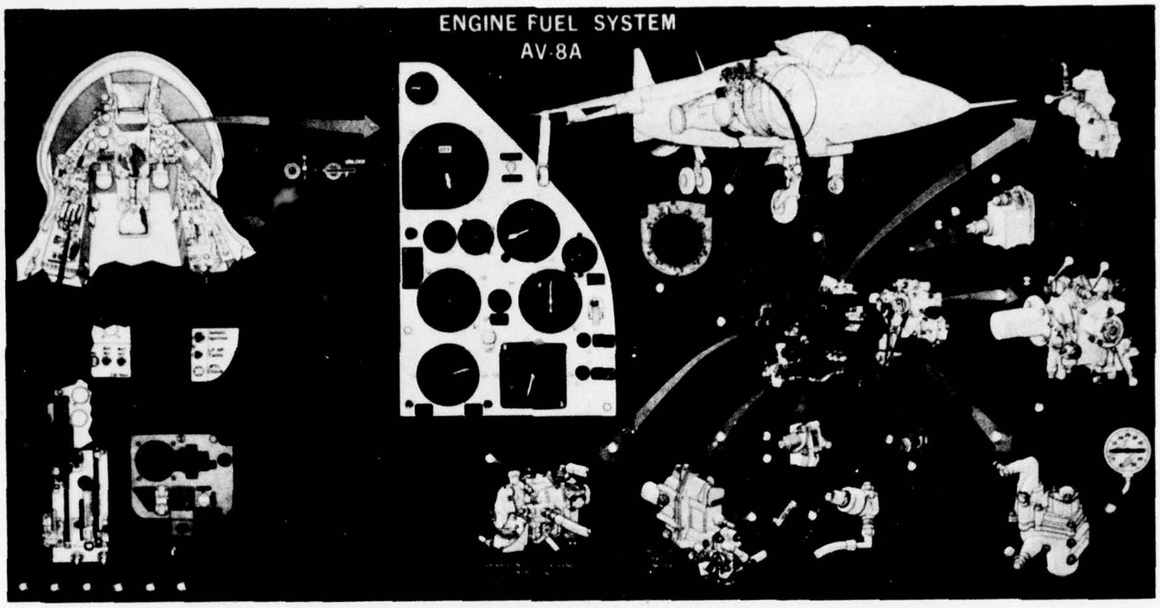

Figure 7. AV-8A Engine Fuel System Display Panel

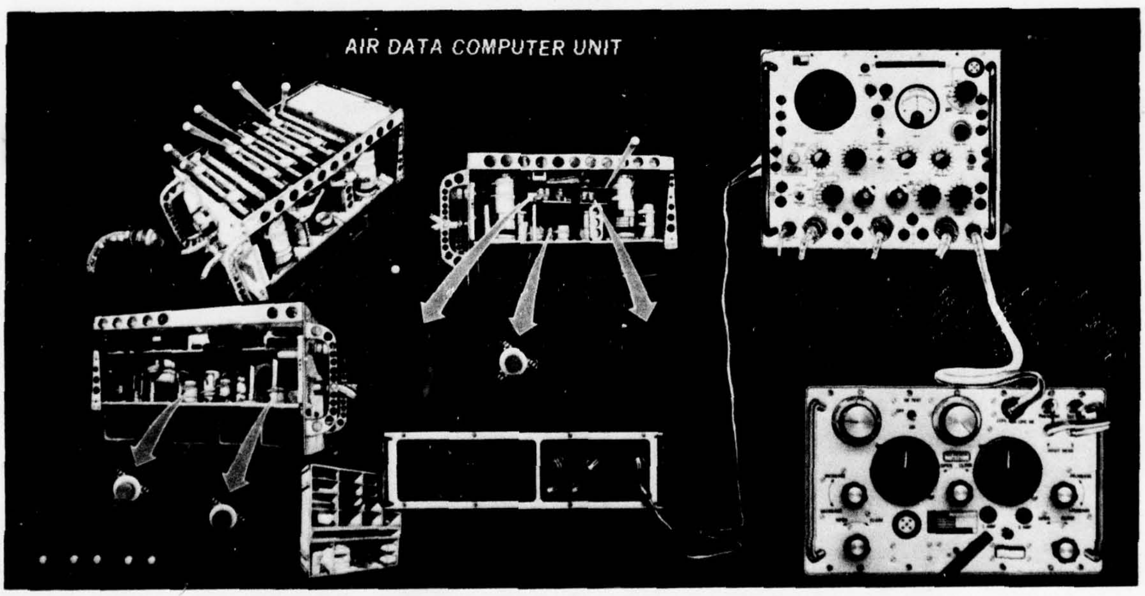

Figure 8. Air Data Computer Unit Display Panel

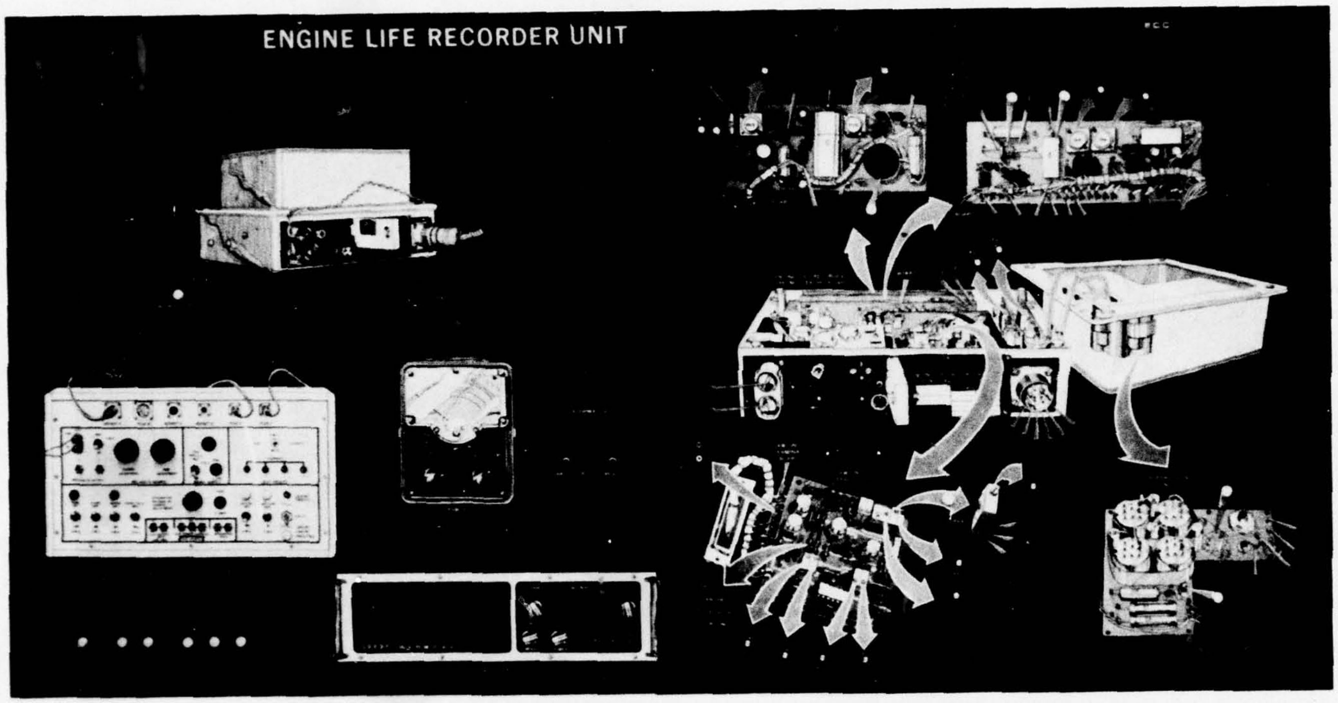

Figure 9. Engine Life Recorder Unit Display Panel

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ABOUT THE AUTHOR

MR. NICHOLAS A. SIECKO is Vice President of the Educational Research and Development of the Educational Computer Corporation, Orlando, Florida, and directs all of the educational projects for the company. He directed the federally sponsored experimental and demonstration manpower training center (Northeastern Pennsylvania Technical Center). Mr. Siecko is a co-holder of the patent for the design of the company's EC II general-purpose simulator and was responsible for establishing the training concepts which are now being implemented. He established the approach used in the design and development of simulation models used with the EC II, and the instructional programs for the SMART simulator. While with the Systems Operations Support, Inc., he developed, prepared, instructed, and evaluated vocational high school technical courses in one of the earlier attempts to apply a systems approach in a public school district vocational technical high school. He was employed by Burroughs Corporation as a Programmer and later as a Systems Analyst on the Atlas Missile Project. Mr. Siecko is a member of the American Society of Training and Development, National Security Industrial Association, and a charter member of the Society for Applied Learning Technology. He has a B.A. degree in Mathematics and has done graduate study in Psychology at the Villanova University.

SIMULATION OF MICROPROCESSOR OPERATION FOR PROGRAM DEVELOPMENT AND CHECKOUT

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INTRODUCTION

This paper is part of work done for the National Science Foundation under Grant GK 42071 titled "Investigation of the application of a hardware parsed recursive string processing language to graphical systems." The aim of this grant is to firmware parse a certain class of input strings in the development of an extensible string processing language similar to text reckoning and compiling (TRAC).[1] During this grant, a full operating language called TOSCL was developed to run on a Data General NOVA 1220.[2,3] The second phase was to implement the parse on the Intel 3000 system.

The primary aim of this paper is to describe the implementation of microprograms using a sixteen bit minicomputer and to show some of the software developed to support microcoding, assembling of microcode, loading the microcontrol store, and the debugging of the microprograms.

The development of Intel's Schottky Bipolar LSI microcomputer elements has brought microprogramming to the field of microprocessors. These devices allow almost infinite variety of design applications, control word size, and control word configuration. This versatility makes the development of support software a difficult if not impossible task.

The emphasis in design and construction of the TOSCL microprogramming system was to be able to microprogram with the least amount of effort. Since the major programming effort was to be the development of TOSCL, only a minimum of software was developed. The minimum support required was (1) a symbolic editor, (2) a microcode assembler, (3) a loader for microcontrol store, and (4) microprogramming debugging aides. This paper shows how these programs combined with hardware functions allowed simulation and debugging of the Intel 3000 microprocessor system.

THE MICROCONTROL WORD

The minicomputer supporting the TOSCL system is a Data General NOVA 1220, and since this is a sixteen bit machine, a control store size of sixteen bits is desirable. The 3000 system configuration suggested by Intel uses an eighteen-plus bit control word (see Figure 1a). To implement a sixteen bit control word, it was necessary to give up some flexibility in the system. After looking into the application which is string interpretation, the facilities considered least critical are portions of the flag control and branching (jumpcode) facilities.

0 1 2	3 4 5 6	7 8 9 10 11 12 13	14 15 16 17	18 . . .
OPCODE	OPERAND	JUMPCODE & DISPLACEMENT	FLAG	K-MASK

1a

0 1 2	3 4 5 6	7	8	9	10 11 12 13 14 15
OPCODE	OPERAND	K	F	C	JUMP & DISPLACEMENT

1b

Figure 1. Microcontrol Word

The resulting control word is sixteen bits (see Figure 1b). It represents a loss of four jump instructions and individual control of one flag bit, the Z-flag bit. The K-buss mask can only be set to all one or all zero.

The most often used 3000 branch command uses the PX inputs of the 3000 system to force a jump in control store. Since this major decision process is accomplished through a hardware decode, the use of one flag control bit is all that is necessary. A reduction in the jump set could be accomplished with the loss of the use of one of the flag functions. Random logic has been added to accommodate this change in the control word format. The 3000 control word jump instruction set is hardware decoded to recover the bits removed by the change in the control word. The I/O signals are also decoded from the NOP Instructions and its operand (function field) to accomplish the required input, output, and memory control.

The resulting control word is sixteen bits (see Figure 1b). It represents a loss of four jump instructions and individual control of the flags.

THE ASSEMBLER

The Intel 3000 system allows such a variety of configurations that the resulting generalized assemblers are often difficult to use, hard to transfer between machines, impossible to implement on small systems, and require large amounts of computer time.

The concept developed was not to generate a general assembler but to use an existing assembler with macro capabilities to define an instruction set which includes both Intel instructions and instructions unique to this task. This loss of portability due to the omission of four jump instructions and the control of the Z-flag was examined and found to be not sufficient to warrant additional efforts. This use of a macroassembler to generate a cross-assembler through the definition of a set of instructions is an efficient approach but results in a highly machine dependent cross-assembler.

The cross-assembler developed to assemble programs for the TOSCL system is run on Data General's macroassembler and has the following format:

(LABLE:) OPCODE(H) (1) OPERAND JUMPCODE DISPLACEMENT

The portion shown in parenthesis is optional. The H appended to the opcode controls the hold of the carry flag. The 1 is used to set the flag output (FO) which is used as the carry input (CI). The label and comment fields are aides for the programmer to use in documentation.

The operand field specifies the range of the opcode and the K-buss information. The operands are broken down into three register groups: (1) register operations, (2) memory operations, and (3) input operations.

The jumpcode and displacement are entirely independent of the opcode and operand. Therefore, the programming techniques for this system are based on established microprogramming techniques.

The output from the macroassembler is in a special binary format. This format can be reduced to a core image file using the relocatable loader. This software along with the symbolic editor is part of the standard system and requires no modification. The resulting core image file can either be executed from the host systems memory or can be loaded into the control store (high-speed random access memory (RAM)) that appears to the 3000 system as a read only memory (ROM).

TOSCL SYSTEM HARDWARE

The current design of the Intel 3000 system used in the TOSCL System is shown in Figure 2. This system uses Intel's suggested system architecture.[5,6] The RAM for the 3000 system is the host system memory and is accessed using direct memory access (DMA). This memory is addressed using the A-outputs of the CPE array, while the D-outputs are used for the write data, and the M-inputs are used to read memory. The DMA operation is automatically initiated by decoding certain 3000 commands (LMM, LMI, LMMH, and LMMIH). If a previous DMA request has not been completed, the instruction will be deferred by halting the clock until the operation is complete. Also to be sure that the microprogram will not try to use DMA results prematurely, the system has a wait-for-memory command (WAIT). The system allows for computation that does not effect significant registers to be performed while the DMA operations are being completed. This may take from 1500 to 3500 microseconds.

The clock circuit can be run in two basic modes, free running and single step. The free running mode once enabled will run until it is halted. The halt can be generated by one of two commands. Done sets the done flag of the host system, and INTR generates a software interrupt to the host system. The clock is also temporarily halted by the second DMA request until the first has been completed. The second mode

of the clock is single step. This allows for the execution of one microinstruction at a time and is used for tracing and debugging programs. The system, when in single step mode, uses the main memory as the source for the microinstructions. For normal operation, the control store memory (256 x 16 bits) is used as the source of microinstructions. This memory can be loaded directly from a core image file which was generated by the cross-assembler and the relocatable loader. The contents of the control store memory can be examined, modified, or verified under program control.

The local memory (16 x 16 bits RAM) is used to jam instructions into the 3000 system. Through the jamming of the proper instructions, all of the registers may be examined. Also the control store address may be examined, along with the contents of control store.

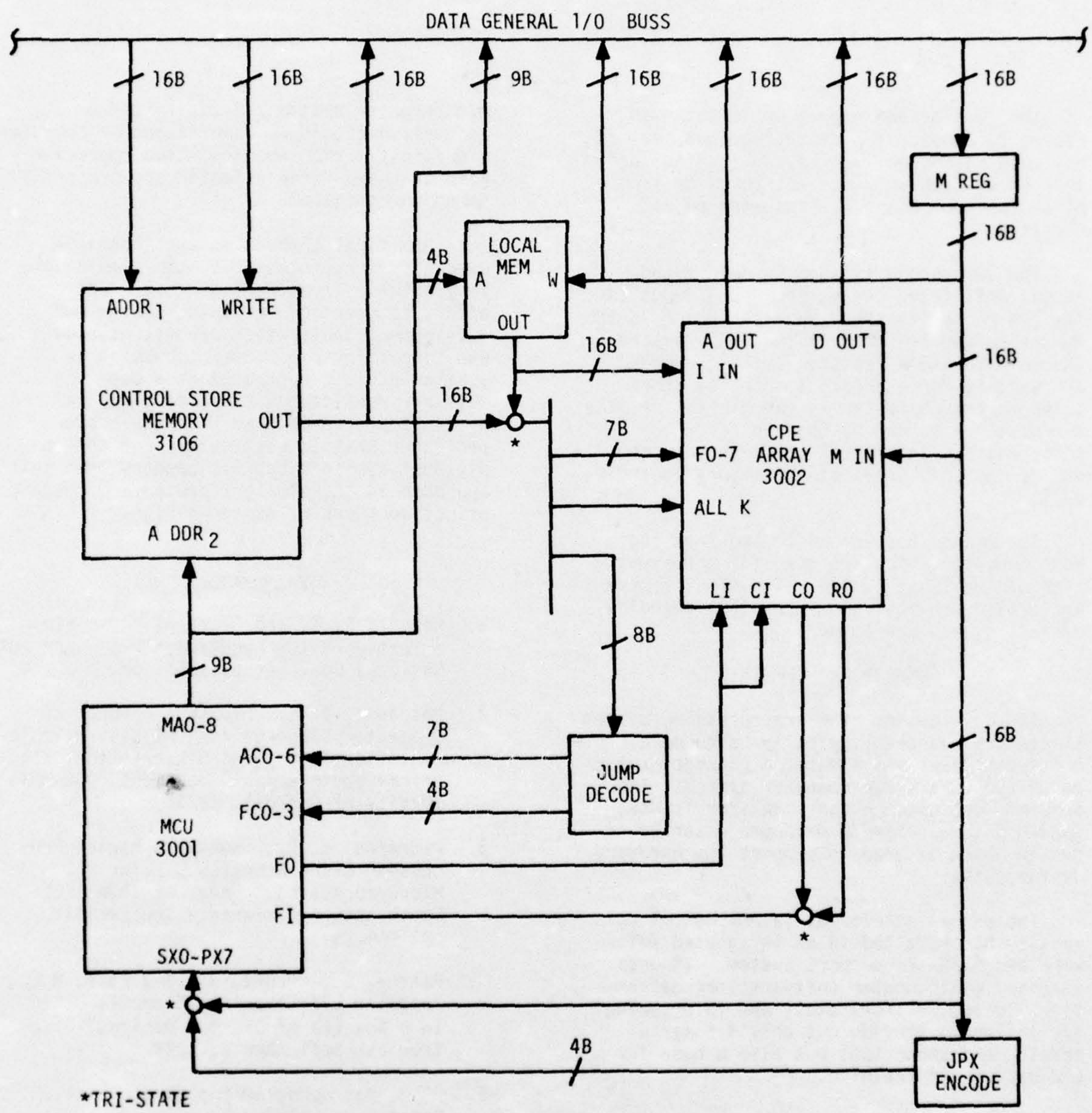

Figure 2. TOSCL System Diagram

MEM OUT	10	11	12	13	14	15	MA	6	5	4	3	2	1	0
JCC	0	0	D3	D2	D1	D0		0	0	0	D3	D2	D1	D0
JCR	0	1	D3	D2	D1	D0		0	1	1	D3	D2	D1	D0
JCF	1	0	0	D2	D1	D0		1	0	1	0	D2	D1	D0
JFL	1	0	1	D2	D1	D0		1	0	0	0	D2	D1	D0
JZR	1	1	0	D2	D1	D0		0	1	0	0	D2	D1	D0
JRL	1	[illegible]	1	1	D1	D0		1	1	1	1	1	D1	D0
JPX	1	1	1	0	D1	D0		1	1	1	1	0	D1	D0

Figure 3. Jump Set and Decode

The jump decode operation is shown in Figure 3, above. The resulting jump set, as has been discussed, is reduced from the original Intel jump set, but was found to accomplish the desired operations with no difficulty.

The JPX encode is used to detect and encode privileged characters. The input to the JPX encode is the M register which is the Memory Buffer Register of the TOSCL system. The word in the M register is then encoded and used to force a jump in control store based on the character in the M register. The M register also can be used to force the first address in control store through the use of the LOAD input of the memory control unit.

The system has inputs to and from the host computer which are used for the simulation of the final system. The final system would also use its own memory thus speeding overall system operation.

SUMMARY AND COMMENTS

The development of microprocessing system simulators has been typically based on a cross-assembler and simulator package designed to run on a large computer system. The program developed on the simulator is then loaded into a separate microprocessor based system which is used to support the hardware design phase.

The effort at Florida Technological University has resulted in an integrated software and hardware support system. It uses standard minicomputer software (macroassembler, loader, editor, etc.) and interfacing facilities to provide not only a powerful development phase tool but also a base for evaluation and training.

Evaluation can be accomplished by adding hardware to gather run time statistics which can then be processed by the minicomputer system. Training can be accomplished using a combination of computer-aided instruction and real-time operation. Both of these "side effects" are presently being investigated.

One final comment on the technique used for microprocessor system simulation; very often a great deal of cost and/or effort is spent on obtaining design and development tools which are essentially a one-time effort. If a minicomputer is available, it can be used as a base for software development aimed at a general system that can be used with the microprocessor that is best suited for the individual application. It appears that this approach is the straightforward and cost-effective means of system design.

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SIMULATION TESTING OF LAUNCH CRITICAL SHUTTLE GROUND SUPPORT EQUIPMENT AT THE LAUNCH EQUIPMENT TEST FACILITY, KENNEDY SPACE CENTER

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ABSTRACT

The National Aeronautics and Space Administration (NASA) is currently developing an economical space transportation system known as the Space Shuttle. Various ground support equipment (GSE) has to perform critical functions to assure a successful launch of the Shuttle vehicle. In order to test this equipment under simulated launch conditions, NASA is activating a Launch Equipment Test Facility (LETF). This facility will simulate effects such as vehicle deflections and oscillations at the pad, rain, cryogenic shrinkage, vehicle lift-off, and solar heating. A physical description of the LETF and its cost-effective utilization is provided in this paper. Test articles, test categories, and test descriptions are detailed. Particular emphasis is placed on simulation equipment and conditions.

INTRODUCTION

Following the successful completion of the Apollo Program, construction efforts on the Space Shuttle launch and landing project started in 1974. The intended purpose of the Space Shuttle Program is to provide an economical space transportation system to carry men, equipment, laboratories, satellites, and propulsion stages to and from Earth orbit. This program is expected to reduce the cost of space transportation to a fraction of the cost of present expendable booster vehicles. Figure 1 shows the Shuttle processing-launch-landing cycle.

Launching a Space Shuttle Vehicle (SSV) involves synchronized operation of launch critical GSE and highly trained launch personnel. The Space Shuttle Program requires testing of launch critical GSE under every possible condition. To provide a testing environment for the equipment, NASA has designed and developed the LETF at John F. Kennedy Space Center (KSC), Florida, which will be used to test GSE under various simulated launch conditions.

The ability of the GSE to react properly under various conditions must be verified prior to committing the equipment to a manned launch. The LETF will be used to test GSE which could cause failure to the vehicle if it did not function properly. Various launch vehicle conditions such as vehicle deflections and oscillations at the pad, rain, solar heating, cryogenic shrinkage, and vehicle lift-off will be simulated by the facility.

FACILITY OBJECTIVES

The primary objective of the LETF is to provide a capability for qualifying and certifying operability, reliability, and maintainability of launch critical GSE prior to installation at the launch complex or between launches when recertification is required. A secondary objective is to provide a capability for development testing of conceptual GSE designs.

JUSTIFICATION

Previous investigations indicated the SSV schedule could be affected by needlessly shipping the GSE back and forth to George C. Marshall Space Flight Center (MSFC) at Huntsville, Alabama, for testing. Using the salvaged Saturn V test equipment from MSFC and erecting this same equipment, modified to Shuttle requirements, at KSC was determined to be advantageous to the Space Shuttle Program in terms of time, cost, and proximity to the launch complex. Hence, it was decided to design and develop the LETF to support tests on access arms, umbilicals, and associated GSE at KSC.

CRITICAL GSE TEST ARTICLES

The LETF will provide the capability for testing, qualifying, and certifying the operation and reliability of the Orbiter access arm (OAA), tail service masts (TSMs), external tank (ET) gaseous hydrogen (GH_2) vent umbilical and access arm, and solid rocket booster (SRB) support/holddown posts. Such equipment is considered launch critical because their malfunction can cause damage to the SSV as well as a mission failure.

OAA. The Shuttle OAA is a modified Apollo swing arm #9. It provides access and egress between the Space Shuttle access tower and the Orbiter vehicle. An environmental chamber is located at the end which interfaces with the Orbiter.

TSMs. The TSMs provide the capability for loading/offloading liquid oxygen (LOX) and liquid hydrogen (LH_2) into the SSV. During lift-off, the TSMs disconnect and retract the T-0 umbilicals from the aft end of the Orbiter and store/protect them within the TSM blast housings from the high temperature exhaust plume and blast loads of the SSV.

ET GH_2 Vent Umbilical and Access Arm. This system allows venting of GH_2 from the ET and achieves umbilical disconnect, withdrawal, and line management as the SSV ET ascends at launch.

SRB Support/Holddown Posts. Eight support/holddown posts will be used for supporting, restraining, and releasing the SSV SRBs during launch. These posts also provide jacking and leveling capability for stacking the SRBs.

TEST CATEGORIES

At KSC, three test categories have been established to separate the testing of Space Shuttle launch critical GSE.

Concept Verification Tests. Concept verification tests consist of a series of tests performed to verify basic theoretical or experimental design principles and concepts. The tests are designed to evaluate the design concepts of critical parts under simulated conditions of operation; confirm adequacy of selection of components and parts; and determine capabilities of equipment under test. Concept verification tests have already been accomplished and successfully completed on TSM and ET GH_2 vent umbilical test articles.

Prototype Tests. Prototype tests consist of a series of tests performed on certain test articles to demonstrate physically its dynamic function, suitability, and reliability. Data is developed from these tests which provide the means to estimate the confidence level of the system to perform its intended function. If acceptable, these prototype test articles may become flight items. A prototype model of the TSM has been designed, fabricated, and assembled and will be tested in the fall of 1976.

Qualification Tests. Qualification tests consist of a series of tests performed on actual flight configured hardware to demonstrate that the design criteria have been satisfied and that the items, as produced, will perform the required functions reliably in accordance with the test criteria.

IMPLEMENTATION PHASES

The LETF project is being accomplished under three phases (Ref. 1).

Phase I Implementation. Phase I implementation includes planning, development, facility design, construction, installation of basic facility equipment, and checkout (Figure 2).

Phase II Implementation. Phase II implementation (Figure 3) is being accomplished under a combined phase IIA and IIB effort. Phase IIA implementation entails planning, development, support systems design, construction, installation of simulation systems and other GSE, and checkout. Phase IIB implementation is a parallel effort to phase IIA which includes refurbishing and modifying the OAA random motion simulator (RMS), TSM and ET GH_2 vent line RMS and lift-off simulator (LOS), and SRB support/holddown posttest fixture. Upon conducting a successful checkout of the test facility under phase II, the LETF will be ready for launch critical GSE testing.

Phase III (Operational). Phase III (Figure 4) includes installation, checkout, and test of the four launch critical GSE test articles, i.e., OAA, TSMs, ET GH_2 vent umbilical and access arm, and SRB support/holddown posts. These test articles are presently being designed, fabricated, and assembled at KSC.

LETF DESCRIPTION

Significant items that comprise the LETF are briefly discussed in the following paragraphs (Ref. 2). Refer to Figures 2 and 3 for relative locations in the LETF of each of the items discussed.

SRB Support/Holddown Posttest Fixture Pad. This pad will support the SRB support/holddown posttest fixture.

OAA RMS Pad. This pad will accommodate

the test equipment which consists of an RMS and an Orbiter skin section. The OAA test will be performed on this pad.

TSM and ET GH_2 Vent Line and Access Arm RMS Pad. This pad will be used for the TSM test and the ET GH_2 vent umbilical and access arm test. A platform is provided to support the simulator for simultaneously testing the umbilical and access arm and the TSM. Figure 5 shows the platform on the pad. The tower simulator is shown in the background.

Tower Simulator. The tower simulator (a three-level section of existing launch umbilical tower #3 approximately 60 ft in height) is supported on four footings. The area immediately under the tower houses the hydraulic pumps for the RMSs and other related GSE. Figure 6 shows the tower simulator, hydraulic pump house, and transformers.

General Pads. Eighteen small general purpose pads measuring approximately 2 ft by 2 ft have been placed as required for electrical cabling, hydraulic, and pneumatic line support.

Pump House. The pump house (Figure 6), located at the base of the tower simulator, includes four 100-gpm motors/pumps, hydraulic oil reservoir, hydraulic charging unit, an exhaust fan, and other ancillary equipment.

LH_2 System. Liquid H_2, supplied from LH_2 tankers, will be used to chill down to cryogenic temperatures the TSM LH_2 umbilical and lines. Hydrogen gas will be vented through the GH_2 vent umbilical and also to the atmosphere. All LH_2 lines are vacuum jacketed.

LN_2 System. Liquid N_2, supplied from LN_2 tankers, will be used to simulate LOX flowing through the LOX umbilical for pressurization.

GN_2 System. Gaseous N_2, supplied from 10,000 psi GN_2 tube trailers, will be used for purging umbilicals, operational intercommunication system communication boxes, ac power distributors, and as a media for system pressurization.

GHe System. Gaseous He, supplied from GHe tube trailers, will be used for purging GH_2 vent umbilical and LH_2 TSM umbilical.

AC Power Distribution System. This system is supplied by a 13.2 kV/480 V - 750 kVA transformer and primary switch. Secondary voltages of 480 V and 277/115 V will be distributed to the pump house, service tower, and test simulators to satisfy ac power and lighting requirements within the test area. AC power is provided to the test control room from existing power panels in Building M7-505.

Control and Monitor System. The control and monitor system is capable of remote control from the test control room (Figure 7) during the ET GH_2 vent umbilical and TSM tests (H_2 flowing). Local control will be provided at the simulator areas (H_2 not flowing).

Cabling. Cabling is routed in trenches covered with steel grating (Figure 8) from the pump house to the control room and simulators. All ac power cabling within the trenches is sealed in high voltage conduit.

Instrumentation. Approximately 350 measurements will be needed to acquire data for functional, qualification, and final verification of GSE/flight hardware interfaces during simulated tests. Instrumentation test equipment will include recorders, transducers, strain gages, load cells, optical instrumentation, flow meters, and other necessary sensors to fulfill all specified conditions of usage. Readings will be analog, digital, and/or actual gage readouts. These outputs will be recorded for complete evaluation of all tests required to support this phase of the Shuttle Program.

Operational Intercommunication System. An operational intercommunication system will be provided at the LETF. The system will be connected into the main system already installed in the Operations and Checkout Building and to the test stands.

TEST SIMULATORS AND FIXTURES

The simulation test equipment was previously located at MSFC, where it was used in the Apollo Program for GSE testing. The equipment was brought by barge in March 1975 to KSC, where the simulators were cost-effectively refurbished and modified for the Space Shuttle configuration.

From calculations based on previous launch experience, the motion of the Orbiter before launch due to various effects such as wind deflections, solar heating, cryogenics, and engine

serious hardware damage.

Upon successful completion of manual testing, the ability of the umbilical carrier to track the simulated Orbiter vehicle motions will be verified. This series of tests will be conducted with the umbilical carrier mated to the Orbiter vehicle RMS. All relative motions between the Orbiter vehicle and the TSMs will be simulated, including the full range of Orbiter vehicle oscillation frequencies and simulated "vehicle fueled" and "vehicle unfueled" conditions. The TSM system will be monitored throughout these tests for binding, chafing, and loosening of components.

The next series of tests will verify proper operation of the TSM system during lift-off simulation. The TSM system will be placed in actual launch configuration and operated automatically during each test cycle. Early tests in this series (with no vehicle random motion) will be conducted with the Orbiter vehicle LOS placed in a nominal, "vehicle fueled" position relative to the TSM. Maximum and minimum vehicle lift-off accelerations will be simulated. Tests will be conducted with the Orbiter vehicle LOS placed in anticipated "extreme" positions with respect to the TSM. Following these tests, random motion of the Orbiter vehicle simulator, at both "nominal" and "extreme" positions, will be introduced with lift-off occurring in conjunction with random motion. As this phase of testing progresses, cryogenic lines will be chilled (using LH_2 and LN_2) prior to lift-off simulation. This series of tests will be completed using chilled lines and simulated rain conditions.

The final series of tests will be similar to those described in the previous paragraph but with the added condition of simulated system failures. Selected portions of the umbilicals and mast disconnect/retract systems will be disabled prior to vehicle lift-off simulation.

ET GH_2 Vent Umbilical and Access Arm Test. Testing of the ET GH_2 vent umbilical and access arm system will commence with proof load tests of the arm structure and measurement of arm deflections. Concurrent with these tests, loads imposed on the fixed-arm platform and tower simulator structure will be determined.

Manual operation of the arm will be performed to verify interfaces and mechanical integrity of the arm components. A series of tests consisting of alignment and adjustment of arm components and arm positioning stops will be performed. Extension and retraction of the arm to verify clearances and interfaces, freedom from binding, as well as locking and latchback verification will be accomplished. The ET skin panel with its umbilical on the LOS structure coupled with the umbilical system (ground side) attached to arm cradles will be cycled throughout its expected motion envelope and monitored for satisfactory operation. Umbilical system operation (under required motion, including launch abort) with all systems functioning, including GH_2 chilldown and simulated rain, will be conducted to verify satisfactory operation. Dynamic operation of the system normal disconnect and disconnect in the back-up mode will be accomplished in the same manner as previously described.

SRB Support/Holddown Posttest. These tests will be conducted to verify the capability of the SRB support/holddown posts to support, restrain, and release safely and reliably the SSV during prelaunch and launch operations.

The SRB support/holddown posttests will be basically structural in nature. Testing under down-loading, uploading, side-loading, and combined-loading will be accomplished. Stress readings and post-deflections will be monitored and recorded. Torque and preload tests of nut and bolt will be accomplished to determine optimization.

Explosive release synchronization tests will be conducted to verify firing of release nuts within the prescribed time prior to simulated SRB ignition and release command. Timing of release will be verified. Certain component failures will be simulated to test the reliability of the system.

CONCLUSIONS

The Launch Equipment Test Facility at KSC provides a cost-effective means for qualification testing of launch critical GSE for the Space Shuttle Program. Use of refurbished and modified simulation test equipment from the Apollo Program has provided considerable cost savings.

System countdown and test procedures will be prepared for LETF testing scheduled to commence in the Spring of

ignition will have been predicted. The TSMs, OAA, and ET vent line will be tested in the LETF to ascertain the capability of these equipments to survive such motion. The simulators used for this function consist mainly of two basic functions, i.e., random motion simulation and lift-off simulation. Random motion simulation is required for testing the TSM, OAA, and ET vent line. Testing the SRB support/holddown posts will be accomplished using a special test fixture designed for that purpose.

Random Motion and Lift-off Simulators. A typical RMS and LOS (Figure 9) consist of a servo-controlled hydraulic/pneumatic resonant drive system, lubrication and cooling systems, and a control system. Random motion in two orthogonal directions in the horizontal plane is simulated by two carriages capable of generating Lissajous figures ranging from a straight line to a circle. Vertical motion is simulated by the LOS. Friction is minimized by using a rail and roller design.

The LOS consists of a tower structure in which two elevator panels ride vertically up and down to simulate the lift-off conditions. Each panel can be controlled independently with its hydraulic drive system. The panels are used for the two TSMs. The OAA flight skin panel is rigidly mounted on the modified tower structure which is attached to the RMS. It has no vertical motion capabilities.

SRB Support/Holddown Posttest Fixture. This is a structural fixture which simulates SRB loads. It uses two hydraulic cylinders to apply test loads to the SRB support/holddown post in two orthogonal directions. These cylinders will be used separately and in combination to test the loading capacity of the holddown post.

TEST CONDITIONS

As required by the Shuttle Master Verification Plan (Ref. 3), testing will be performed under conditions simulating vehicle motion before launch, fueling and purging, system power-up/power-down, emergency, hold, and other situations.

Launch environment is affected considerably by rain, solar heating, cryogenic effects, Orbiter deflections and oscillations, and vehicle lift-off. Satisfactory operation of the launch critical GSE has to be insured under such a wide range of conditions. The LETF will simulate these effects and will be used to investigate the response of GSE under these simulated launch conditions.

DESCRIPTION OF TESTS

OAA Test. Testing the OAA system will commence with proof load tests of the arm structure and measurement of arm deflections. Concurrent with these tests, loads imposed on the tower simulator structure will be determined.

A series of tests consisting of alignment and adjustment of the OAA components will follow the load tests. The interface between the environmental chamber on the arm and the Orbiter skin panel attached to the RMS will be checked, and the arm positioning stops will be adjusted accordingly. The operation and adjustment of the latchback mechanism equipment on the OAA and tower simulator will be verified. Furthermore, all components will be checked for free movement and interference during arm rotation.

The OAA will be extended toward the Orbiter skin panel which is attached to the RMS, and the loads imposed on the Orbiter will be determined. The seal between the environmental chamber and the Orbiter skin panel will be monitored for satisfactory operation.

The operation of the OAA rotation system will be verified in a series of manually and automatically controlled tests. Moving the OAA to the extend and retract positions will be tested with the Orbiter skin panel in various positions. Certain component failures will be simulated to test the reliability of backup systems.

Testing will include verification of the systems serving the environmental chamber, i.e., environmental controls and electrical/communications equipment. In addition, rain conditions will be simulated with and without vehicle motion simulation.

TSM Test. Testing of the TSM system will commence with manually controlled operation of the umbilical disconnect and retract mechanisms. Proper operation of the retract mechanism will be verified. These tests will validate the operation of the various mechanisms. Since they are conducted manually, tests can be quickly terminated in event of malfunction to preclude

1977. These procedures will be used by technicians and launch operations personnel to perform the qualification tests. Testing and subsequent required changes/modifications will "debug" the systems and qualify them for manned launches of the SSV. The training and experience acquired by technicians and launch personnel on the LETF operation will qualify them for launch complex operations during an actual manned launch.

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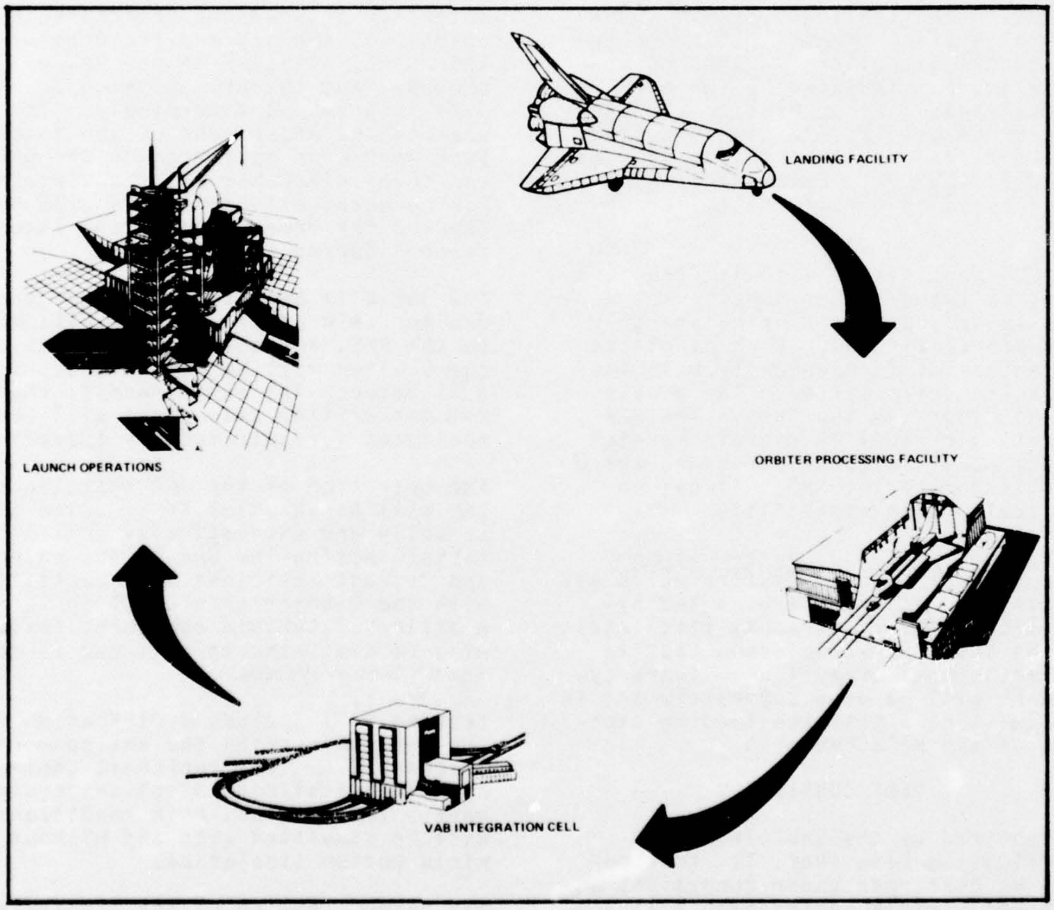

Figure 1. Shuttle Processing-Launch-Landing Cycle

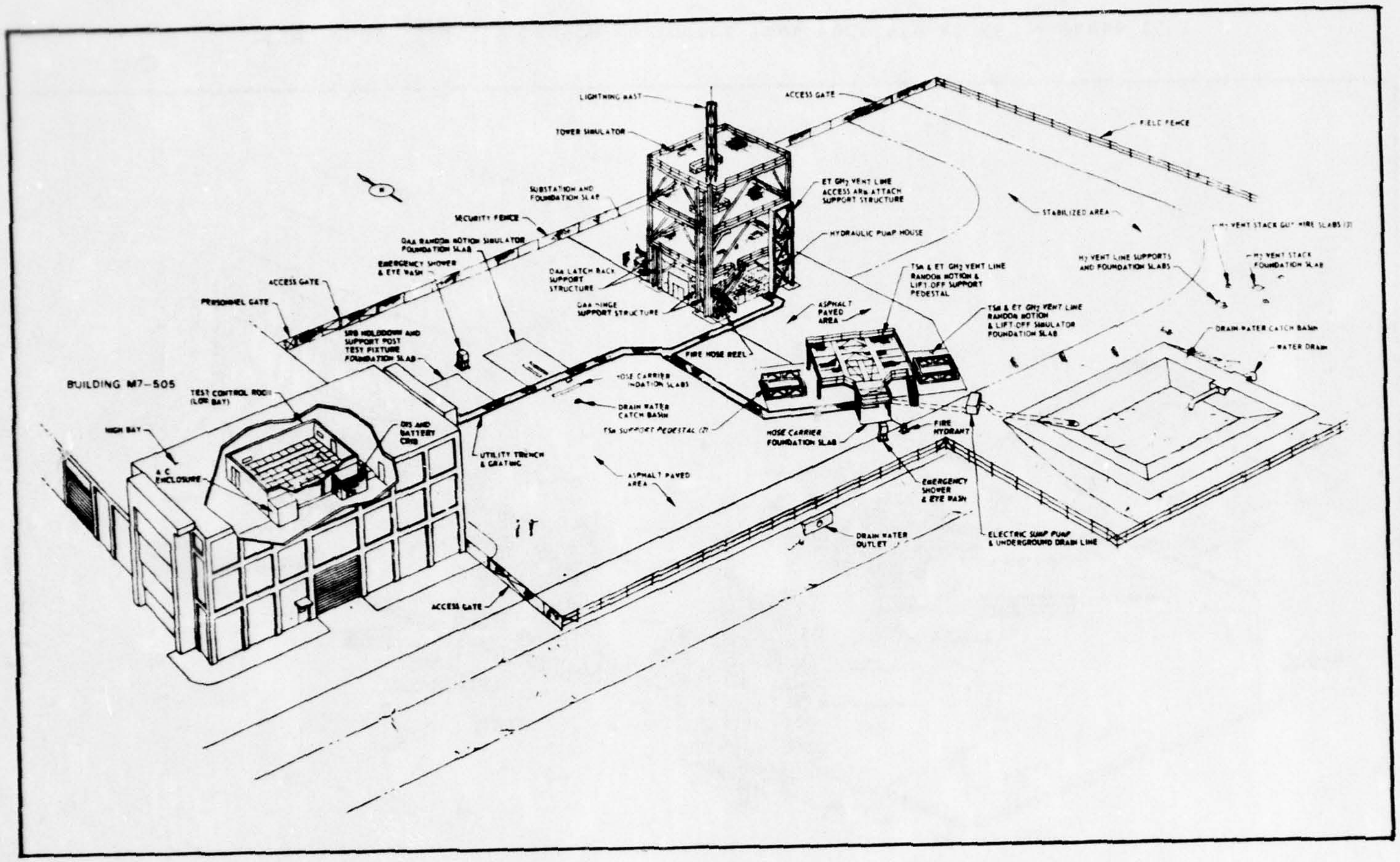

Figure 2. Shuttle Launch Equipment Test Facility at KSC - Phase I

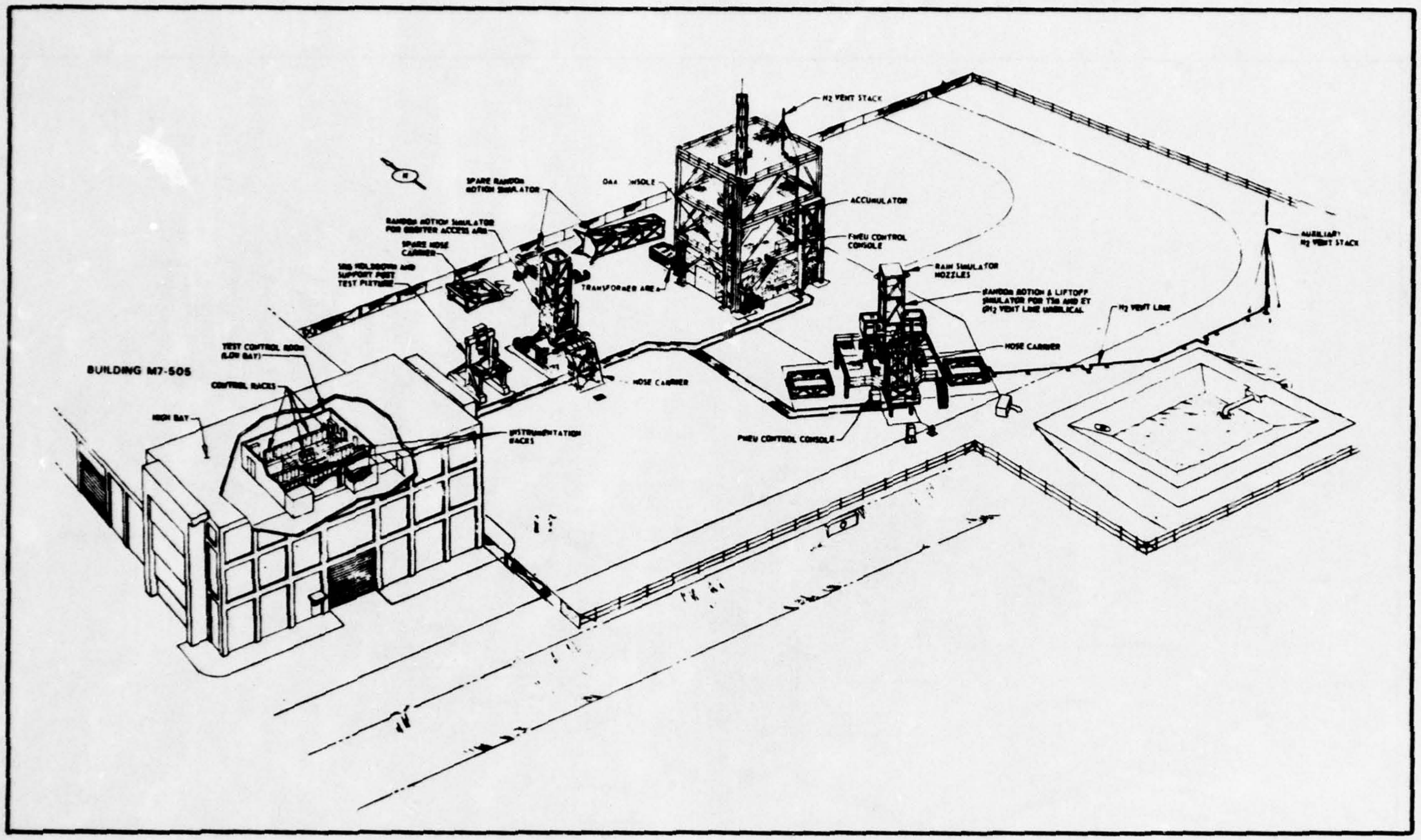

Figure 3. Shuttle Launch Equipment Test Facility at KSC - Phase II

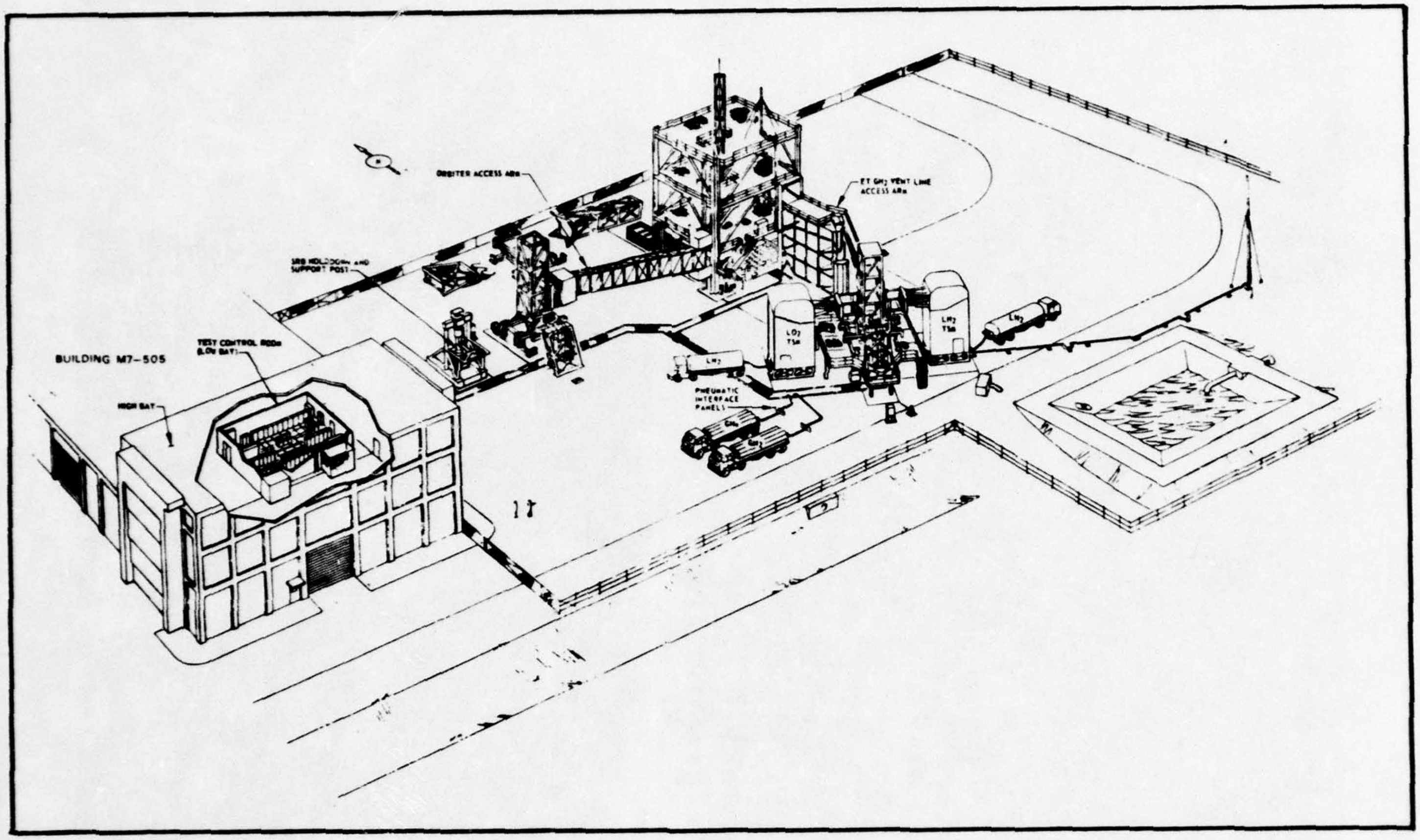

Figure 4. Shuttle Launch Equipment Test Facility at KSC - Phase III (Operational)

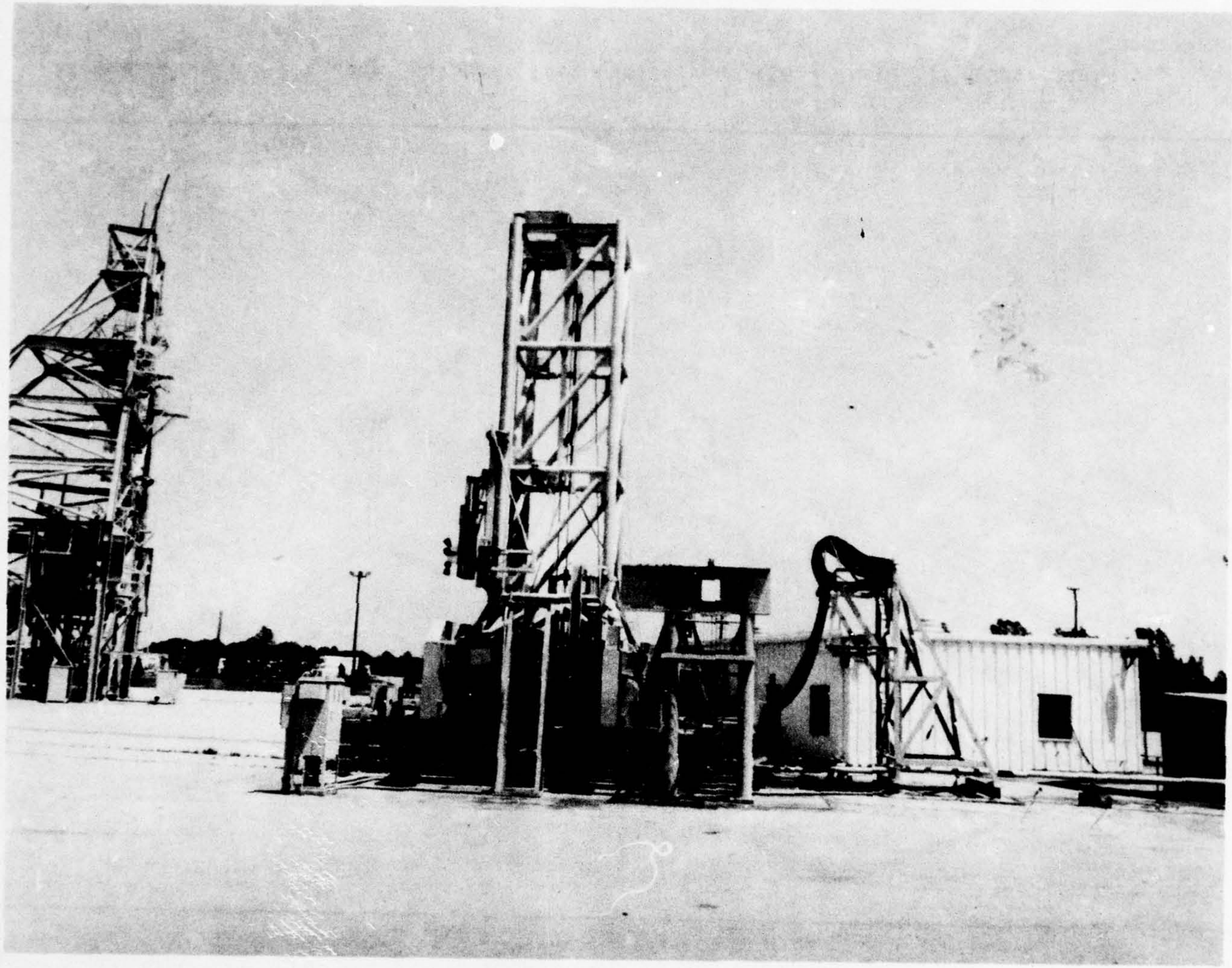

Figure 5. TSM and ET GH_2 Vent Line Access Arm - RMS Pad with Pedestals (TSM and RMS) and Tower Simulator in Background

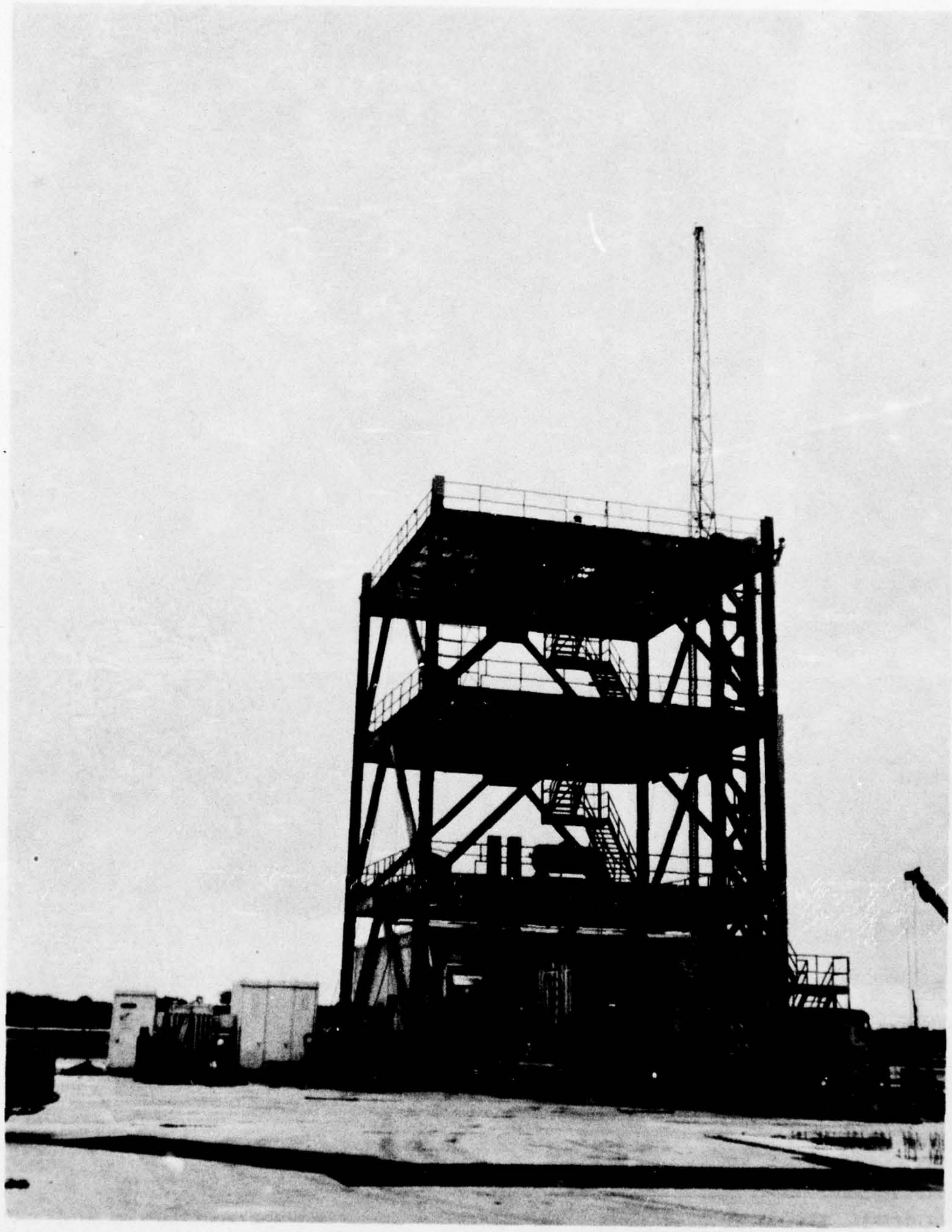

Figure 6. Tower Simulator, Hydraulic Pump House, and Transformers

Figure 7. Test Control Room

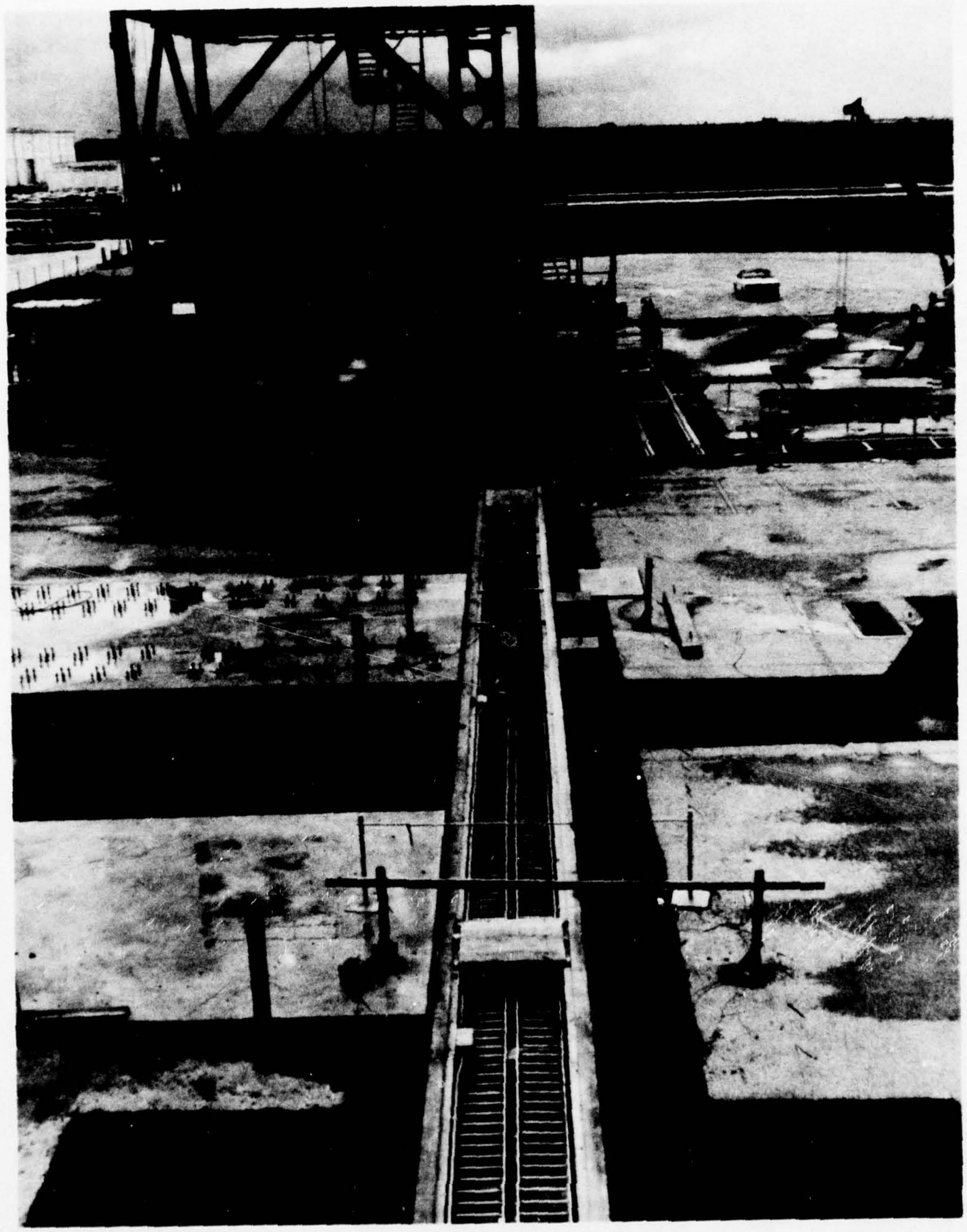

Figure 8. Cable Trenches with Steel Grating

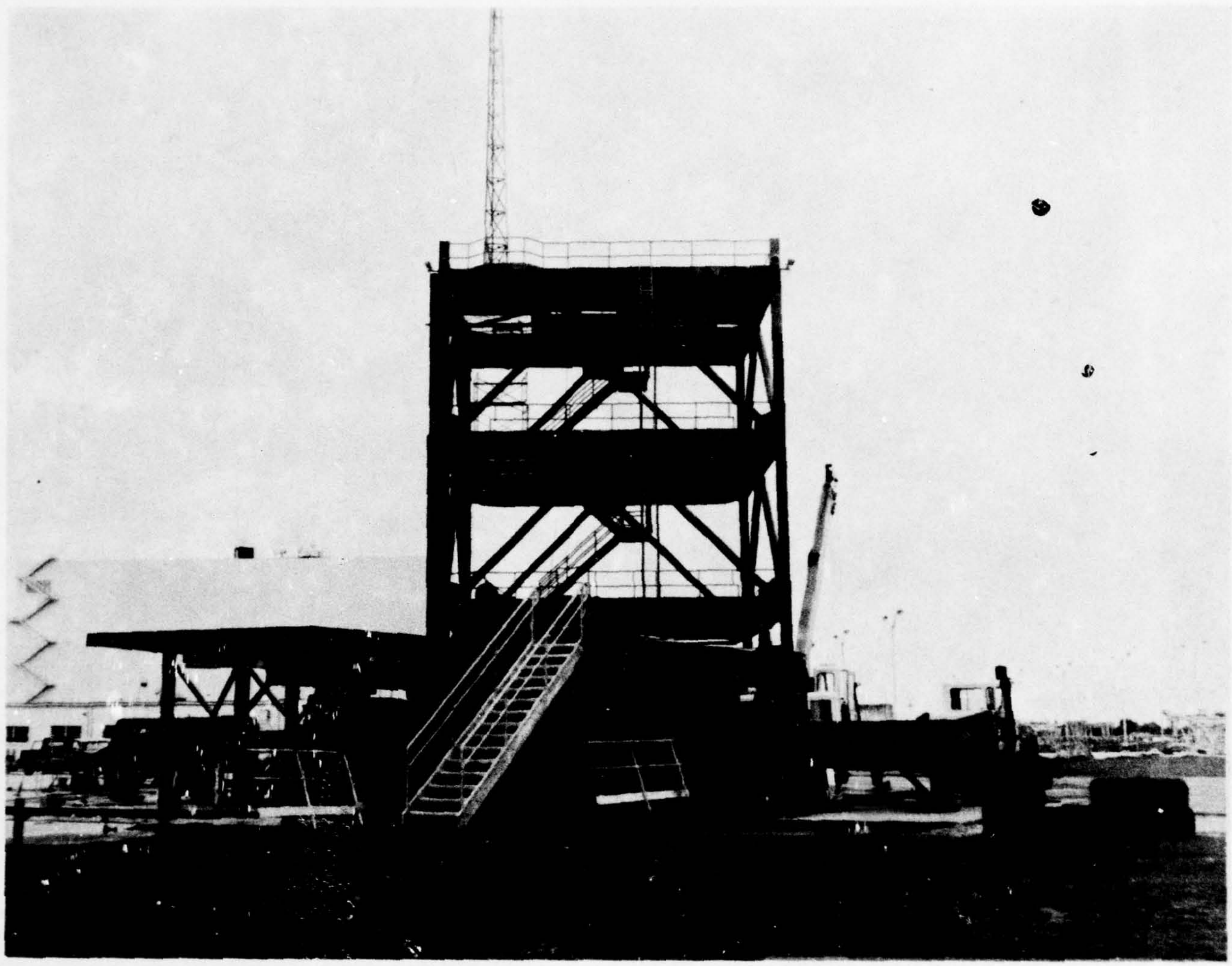

Figure 9. A Typical Random Motion and Lift-off Simulator

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A PROCEDURAL PROPOSAL FOR RELATING TRAINING DEVICES TO JOB SPECIFICATIONS

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For a number of years, the related problems of establishing training device requirements and evaluating the ability of a device to deliver the improvements in student performance expected of it, have been widely discussed. The Chief of Naval Education and Training Support (CNETSUPPORT) Instruction 1551.5 identifies approved procedures for conducting a training situation analysis to establish the training specifications and/or military characteristics (MCs) of a device. Efforts to develop and systematize Transfer of Training Effectiveness Evaluation (TTEE) procedures have already been documented[1] and are continuing with technical reports expected shortly. Despite these and related efforts, there appears to be within the device procurement/validation process, a noticeable paucity of effort directed toward the goal of assuring that a device fills a viable fleet need. And yet, within the available literature, there exists a common thread, specific behavioral objectives (SBOs), which, properly recognized and seized upon, will yield a systematic approach and provide documentation of each device's validity in terms of the needs of the fleet. Recently, Naval acceptance of the Interservice Procedures for Instructional Systems Development (IPISD), NAVEDTRA 106A, has added new and consolidated familiar procedures for systematic curriculum development and, hence, for coordinated device procurement.[2]

Historically, training devices have been requested, designed and verified with scant input from curriculum development activities. Military characteristics form the base line requirements for a device. While Naval Training Equipment Center Instruction 3910.4, Military Characteristics; instructions and responsibilities for, of 1 July 1969 does refer to training objectives, a review of military characteristics for randomly selected devices indicates that, in practice, this has not been interpreted to refer to specific behavioral objectives. Rather, objectives for the device have been identified and documented. It would appear that clarification and amplification of the need to include behavioral objectives in the military characteristics document is necessary.

As Lawrie and Boringer point out[3] a typical sequence of events leading to the implementation of training often lacks validity because failure to specify what is needed makes the attempt to determine what the results are a subjective effort at best. Usually, this is due to the inability of the requestor to provide complete documentation and full explanation of the training requirements, i.e., the training objectives and the job tasks upon which they are based, which necessitated the initiation of a request for device procurement, This situation exists despite acceptance of the philosophy that

> "The value of any land, surface, subsurface or flight training equipment . . . must rest on the suitability of its design for a particular training application and the appropriateness of the manner in which it is used."[4]

With the adoption of the IPISD methodology, the potential exists to objectively "study a training system as a whole, including curriculum, training personnel, training population and training environment . . . ."[5] This study will provide future contractors with specific information concerning both the expectations for the device and the process which will be used to objectively evaluate that device in terms of the identified expectations.

Two major alterations will, however, have to be made in the procurement process if the benefits of systematic course design are to accrue to the design of training devices. The first is the addition, to the Program Manager's staff, of Education Specialists or other personnel who are familiar with the IPISD process. The second is the inclusion in the contract of requirements that the device under consideration reflect documented and acceptable expectations for student performance as identified by specific behavioral objectives. In cases where a curriculum does not exist at the time of the device request, these requirements should be related to the job task inventory for which students are being trained. In either case, evaluation would include a comparison of job performance of students who received training on the device with those who had not had such training.

Taking the first proposed modification to the procurement process, it is apparent that, in order to ensure full understanding of the specific education and training requirements addressed by the device request, input from personnel fully cognizant of the IPISD process will be vital. While

curriculum development expertise has, on occasion, been a part of past efforts to develop devices, this input has not been routinely sought at the conceptual design phase nor has it always been sought at any point in the procurement process. Additionally, when the input of curriculum development experts has been sought, it has often been for purposes other than the determination of the most effective means of integrating a proposed device into the total training system. The results of this oversight have not necessarily been poor or ineffective devices; they have, however, at times been devices of questionable benefit to the training mission of the requesting command and, therefore, to the needs of the fleet.

At present, a Program Team must include an Engineering Member, an Integrated Logistics Support Member and a Human Factors Member.[6] By requiring, in addition, that the Program Team include a member representing IPISD expertise, the likelihood that the conceptual design of the device will be reflective of identified training needs and of the current state-of-the-art in educational technology will be greatly increased. The IPISD specialist will be able to bring to the Program Team a depth of knowledge concerning the process of curriculum development which is not available from other sources. This knowledge should be an integral part of any effort to establish device characteristics because during this phase the relationship between the device and the course content must be established. To date, the design process has not always been able to document the closure of this portion of the development loop. Doing so, through the inclusion of IPISD expertise, will greatly enhance the total device procurement process and make the end product of that process a more complete and fully documented reflection of the requestor's needs.

The second change suggested will be of increasing value as the IPISD approach to curriculum development is more fully implemented. Once a curriculum is established according to the procedures outlined in NAVEDTRA 106A, it will be of the greatest importance to reflect the output of that development effort in the design of training devices. By requiring that the contractor design toward student attainment of specific behavioral objectives as reflected in the Military Characteristics, the value of the device will become readily apparent to all, regardless of their degree of familiarity with the curriculum, the device or the job to which both are related. Additionally, the contractor will be provided with more specific goals which will allow him to estimate the initial cost of the device with greater accuracy and against which his performance can be evaluated with greater objectivity.

The IPISD approach requires that curriculum designers begin with an identification of what is and what should be the practice in operational units. It further requires full documentation of the steps which lead from the needs of the job to the content of the curriculum. A natural extension of this process is the continued documentation of the steps which lead from the curriculum to a device request and, ultimately, to the device itself. Full realization of the goals of IPISD in the design of curricula, then, will yield a pool of information which will permit the development of devices directly related to the jobs performed in the fleet. That this requirement will prove advantageous is readily apparent. The difference between the accepted practice and that suggested by this paper is one of specificity. The following sample format should suffice:

SBO	MC
Given . . . The student will be able to interpret sonar presentations of whales without error.	Full reproduction of sonar return from whales with degrees of background noise ranging from 1 to 125% of normal.

As can be seen, there exists in this example, a direct relationship between the military characteristics and a specific behavioral objective taken from a hypothetical curriculum. In practice, a given military characteristic may be derived from a number of objectives. Conversely, a single objective may be part of the justification for a number of military characteristics. Nevertheless, the end result should be a conceptual design for the device which makes those interrelationships obvious. With this documentation in hand, there will exist a straight line of identifiable needs from the device as it exists on-site to improve training to the fleet user whose personnel require training to improve job performance.

While it has long been recognized that " . . . a systematic approach to evaluation (of training) can move in the direction of exactness only if it is related to specific objectives. . ,"[7] little has been done to ensure the application of this principle to training devices. The approach herein suggested will ultimately permit the military training community to take a more active role in the establishment of acceptance test criteria through the logical extension of the required performance standards (contained in Specific Behavioral Objectives [SBOs]) to the analysis of

device-related student behaviors. (It should be pointed out that this statement is not intended to imply that present considerations of device reliability, flexibility of design, etc., should be overlooked or even relegated to a position of secondary importance. It is, however, intended to suggest that there is a broad area of concern, i.e., student performance, which is not given the status it should have in the area of acceptance testing.) The dual impact of the inclusion of curriculum design expertise on the conceptual design team and the marriage of military characteristics to specific behavioral objectives may finally yield a closed-cycle beginning and ending with the identifiable needs of the fleet.

There are, of course, other benefits to be derived from such an approach. Reliance on fully documented specific behavioral objectives in establishing device requirements may well lead to cost savings in several broad areas. In the design of a device, any effort to limit complexity should certainly lead to decreased initial procurement cost. By limiting the proposed functions to those which are demonstrably a part of the curriculum and no others, the design problems resulting from overly sophisticated hardware and software can be substantially reduced. It is further apparent that, to a point, maintenance costs and downtime for the device will be reduced through function simplification.

Another likely advantage is that of reduced personnel requirements in a number of categories. If students obtain course objectives more quickly, the training pipeline is shortened, allowing for greater student throughput within existing facilities with consequent reductions in the cost of training each individual. If the device aids in presenting vitally important subject matter more effectively, instructors are freed to return to operational billets. And, if the device is easier to maintain, personnel are freed from the school house and made available to improve fleet readiness.

The mechanics for implementing these changes already exist and their routinization will involve little, if any, additional cost to the present process of device procurement. The planning conferences at which IPISD inputs are vital are presently held on a scheduled basis. The training objectives to which the device should be oriented either already exist or will be developed independent of the device procurement process through the implementation of IPISD methodology. Information on student performance is, or should be, available and will continue to be gathered by the requestor allowing for objective analysis of the device's effectiveness without increased workload or cost. Finally, implementation of the techniques developed in the Interservice Procedures for Instructional Systems Development will provide a continually expanding data bank which will facilitate verification of the applicability of training devices to job performance.

Whether or not this proposal will yield the predicted benefits can only be determined through a practical application of the approach presented. The most logical first step would be to choose a minor device request requiring development of a new training device which, while unique, is similar in many of its major parameters to an already existing device. By comparing the end result of a procurement process based on specific behavioral objectives with one not so based, determination of the effectiveness of this proposal can be made. To ensure that such determination is effective and objective, the use of the expertise of such an organization as the Training Analysis and Evaluation Group (TAEG) in conducting comparative studies of the training effectiveness of the two devices should be considered. If, in this case, the approach suggested by this paper proves of substantial benefit, another trial on a more sophisticated device, such as one of the 14A2 series or a flight simulator, could then be undertaken. Eventually, the approach could, if successful, be applied to all device procurement efforts.

In summation, present efforts to identify the validity of device requests and to evaluate the effectiveness of the device within the total training setting recognize the necessity to relate procurement and evaluation to specific behavioral objectives. A systematic approach which will allow curriculum developers to enter the procurement cycle at the conceptual design phase is needed. Their input will help ensure the training relevance of the contract specifications. Further, the contract itself must reflect the recognized place of specific behavioral objectives in determining training requirements and in establishing evaluative criteria. Among the potential benefits of such a system are:

a. Improved contractor performance through increased understanding of the goals envisioned for the device.

b. Potential savings across a broad spectrum of cost areas.

c. Increased fleet readiness through more job-specific device requirements.

By beginning now to base development of devices directly on specific behavioral objectives, the Navy can ensure that its training devices will relate, through the curriculum they are a part of, to student performance both in the school house and in the fleet. This relationship will ensure that training devices support the needs of the fleets and the overall mission of the Navy, a necessary step toward total readiness afloat.

FOOTNOTES/REFERENCES

1. Melvin Frietag, Ph.D., "Transfer of Training Effectiveness," CAMPUS, December, 1975, pp. 30 - 32.

2. It is assumed, for the purposes of this paper, that a device exists solely to fill a perceived need in a new or existing curriculum.

3. Clayton W. Boringer and J. W. Lawrie, "Training Needs Assessment and Training Program Evaluation," Training and Development Journal, November, 1971, pp. 6 - 9.

4. Chief of Naval Education and Training Support, CNETSINST 1560.2, Subj: Transfer of Training Effectiveness Evaluations; policy and doctrine for, (Pensacola, Fla.: June 4, 1974, para 3.h.

5. Ibid., para 3.f.

6. Naval Training Equipment Center, NAVTRAEQUIPCENINST 3910.4, Subj: Military Characteristics; instructions and responsibilities for, (Orlando, Fla.: July 1, 1969).

7. Lloyd L. Byars and Donald P. Crane, "Training by Objectives," Training and Development Journal, June 1969, pp. 38 - 48.

8. Chief of Naval Education and Training Support. CNETSINST 1551.5, Subj: Training situation analyses; procedures for conducting, 27 January 1975.

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